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U. S. ARMY. CORPS OF ENGINEERS  
EVALUATION OF PATERSON CLOROCCEL  
STERILISER



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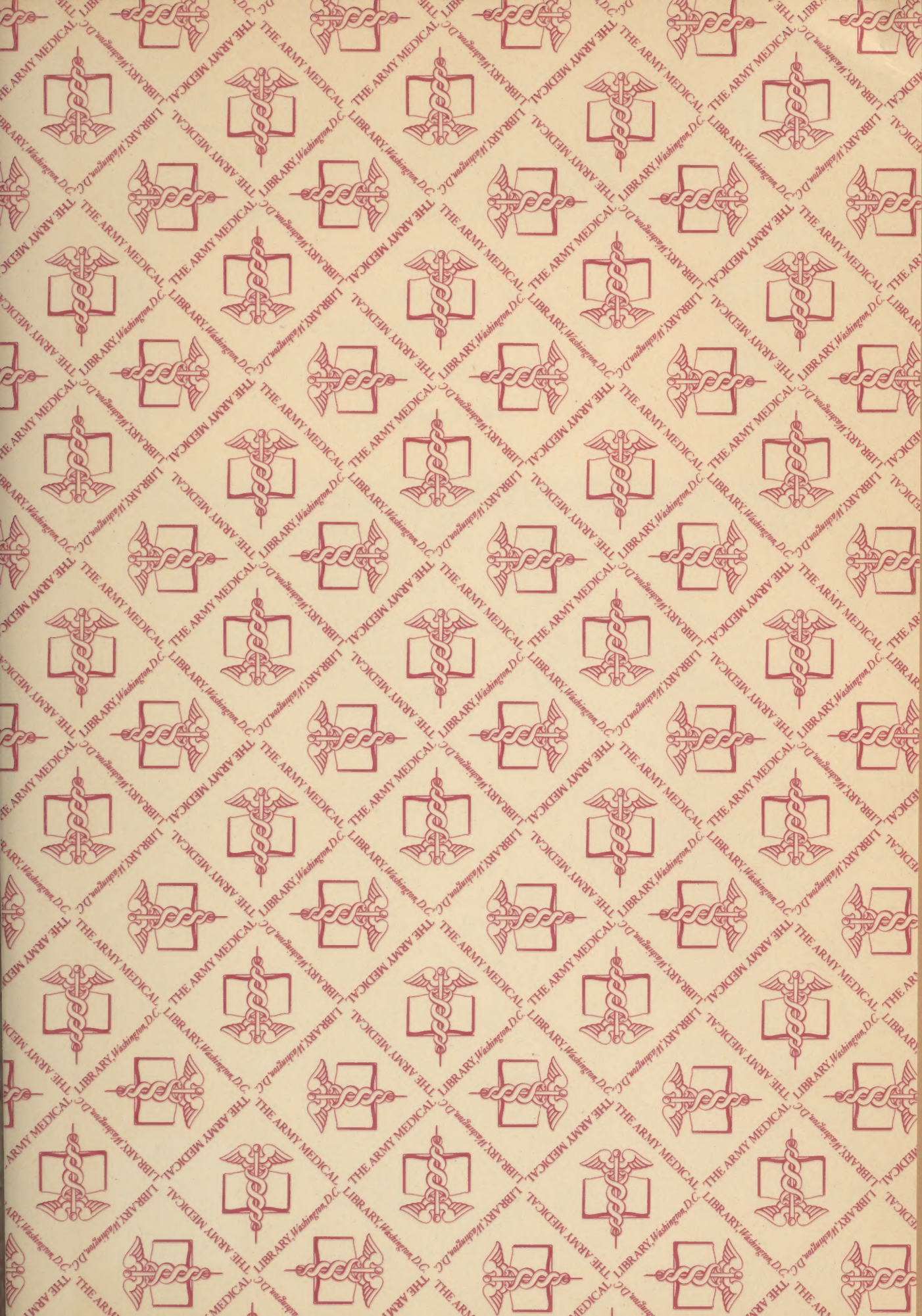


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*ENGINEER RESEARCH  
AND DEVELOPMENT LABORATORIES*

Report 1108

EVALUATION OF  
PATERSON CLOROCCEL STERILISER

Project 8-75-05-003

1 April 1949

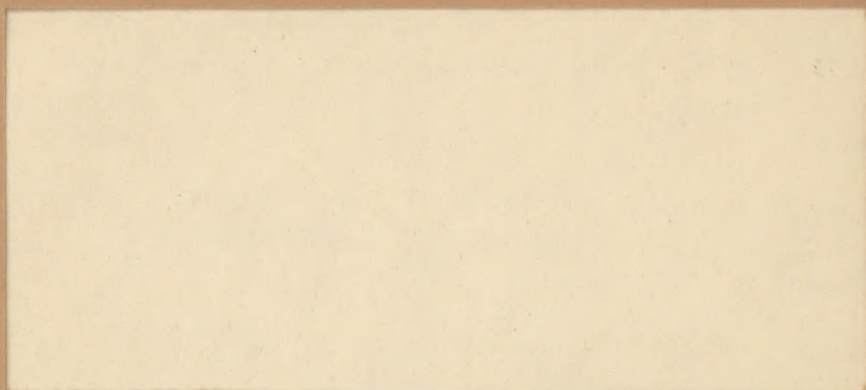


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*DEPARTMENT OF THE ARMY  
CORPS OF ENGINEERS  
ENGINEER RESEARCH  
AND DEVELOPMENT LABORATORIES*

*THE ENGINEER CENTER  
FORT BELVOIR, VIRGINIA*







ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES

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EVALUATION OF  
PATERSON CLOROCCEL STERILISER

Project 8-75-05-003

1 April 1949

Submitted to

THE CHIEF OF ENGINEERS, U. S. ARMY *Corps of Engineers*

by

The Commanding Officer

Engineer Research and Development Laboratories

Prepared by

Don C. Lindsten  
Ernest H. Sieveka  
Water Supply Branch  
Engineer Research and Development Laboratories  
Fort Belvoir, Virginia



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## SUMMARY

Subject. This report covers the results of a laboratory and field evaluation of the Paterson Clorocel Steriliser, an electrolytic sodium hypochlorite producing unit.

Conclusions. The report concludes that:

1. The Clorocel can be operated satisfactorily with sea water.
2. The Clorocel is sufficiently simple in operation so that military personnel in the field can operate it with a minimum amount of training.
3. The Clorocel can be operated satisfactorily with an automobile type d-c generator.
4. High test calcium hypochlorite is superior to electrolytic sodium hypochlorite for military field use for the following reasons:
  - a. It requires a lesser weight and volume of raw materials to produce a given amount of available chlorine than does the electrolytic method.
  - b. Special equipment such as an electrolytic cell, a generator, or other source of power is not needed.
5. Under conditions where the normal supply of calcium hypochlorite is exhausted and a ready supply of common salt or sea water is available, the Clorocel is considered a satisfactory emergency source of hypochlorite.

Recommendations. The report recommends that:

1. Current investigation of electrolytic sodium hypochlorite equipment be terminated.
2. The unit be standardized if a future requirement for special military situations exists.







## EVALUATION OF PATERSON CLOROCCEL STERILISER

### I. INTRODUCTION

1. Subject. This report covers the results of a laboratory and field evaluation of the Paterson Clorocel Steriliser, an electrolytic sodium hypochlorite producing unit.

2. Authority. Authority for the investigation, which was carried out under Project 8-75-05-003, is contained in the first indorsement to a letter from the Office of the Chief of Transportation to the Chief of Engineers, dated 20 August 1947, file TCRAE-M 414/400.112, subject: Test of Chloro-O-Cel Unit, with 1 inclosure. A copy of this letter, together with the project card (RDB Form 1A) for Project 8-75-05-003, appears in Appendix A in this report.

3. Personnel. The work on the evaluation of the Clorocel Steriliser was carried out under the direction of E. H. Sieveka, Chief, Water Treatment and Laboratory Section, Water Supply Branch. Preliminary laboratory tests were made by C. D. Gates at Fort Belvoir, Virginia. Detailed field tests were made at Fort Story, Virginia, by D. C. Lindsten in cooperation with R. G. Hahl, Chief, Distillation Test Section.

4. Source Material. An investigation of the literature was undertaken to obtain theoretical information on the production of sodium hypochlorite by the electrolysis of NaCl and to learn details of the design and operating characteristics of similar cells that have been constructed. A summary of literature on electrolytic hypochlorite Clorocel cells is included in Appendix B.

5. Applications of an Electrolytic Hypochlorite Cell. Chlorination is the standard method of water disinfection in the U. S. Army. For this purpose, chlorine is used either in the liquid form or in the solid calcium hypochlorite form. The major part of the chlorination in the Army field units is done with calcium hypochlorite which has a high available chlorine content (70 percent) and is a dry, readily transportable salt. Difficulty is experienced, however, with container corrosion and loss of chlorine strength during long storage, especially at elevated temperatures and in humid atmospheres. Sodium hypochlorite releases available chlorine in the same manner as does calcium hypochlorite and is a very popular commercial disinfectant (i.e., Clorox), but it is seldom used in water purification because it cannot be obtained in stable crystalline form and must be transported as a water solution. Sodium hypochlorite can be produced electrolytically from a solution of ordinary table salt (sodium chloride) by means of an electrolytic cell that is simple in construction and can be operated in the

field. This method eliminates the transportation of heavy liquid solutions. The required raw material is not expensive and usually is readily obtainable, sea water serving as an excellent source of raw material at no cost for ocean-going ships or for Army sea water distillation units in which chlorination of the distillate is required.

6. Use in British Army. The British Army used as part of its field water purification equipment an electrolytic sodium hypochlorite cell. The British field manual, Handbook, Provisional, of the Water Purification Sets, Mobile MK I, 1940, describes in detail a portable water purification set which uses an electrolytic cell. This mobile set, mounted on a  $1\frac{1}{2}$ -ton truck, is intended to be used in certain tactical situations where the regulation unit water trucks are at a disadvantage. The set consists of a steriliser unit, a pump and generator, a filter, two gasoline engines, and the necessary hose and chemicals. No provision is made for storing water, as the set is used only for filling water trucks or existing water tanks.

The steriliser unit consists of an electrolytic cell for producing sodium hypochlorite from common salt. The salt is dissolved in water, the solution is drawn through the cell by means of an injector operating off the positive side of the water pump, and the hypochlorite solution is injected into the suction side of the water pump. Control of the hypochlorite concentration is obtained with a rheostat in the shunt field of the generator that can be used to vary the amount of current passing through the cell. The steriliser unit also contains an ammonium sulfate injector for injecting ammonium sulfate solution into the suction side of the water pump. The ammonia combines with the hypochlorite to form chloramines. Chlorine residuals can be maintained for a longer period in the presence of ammonia, hence, provide better protection during distribution of the water. A similar result is obtained in the American field units by the use of ammonia alum.

The pump, a Mono positive rotary type capable of handling 3000 gallons of water per hour, and the generator, a drip-proof type rated at 45 amperes, 4 to 10 volts, and 1800 rpm, are both driven by a portable gasoline engine rated at 8 bhp. The filter is the usual type of diatomite unit.

In their current development projects, the British are continuing the application of the electrolytic method for producing chlorine in the field.

According to Royal Engineer manuals it is indicated that the British also use a low test bleach (25 to 30 percent available chlorine) as a chlorinating agent in their regulation units. What



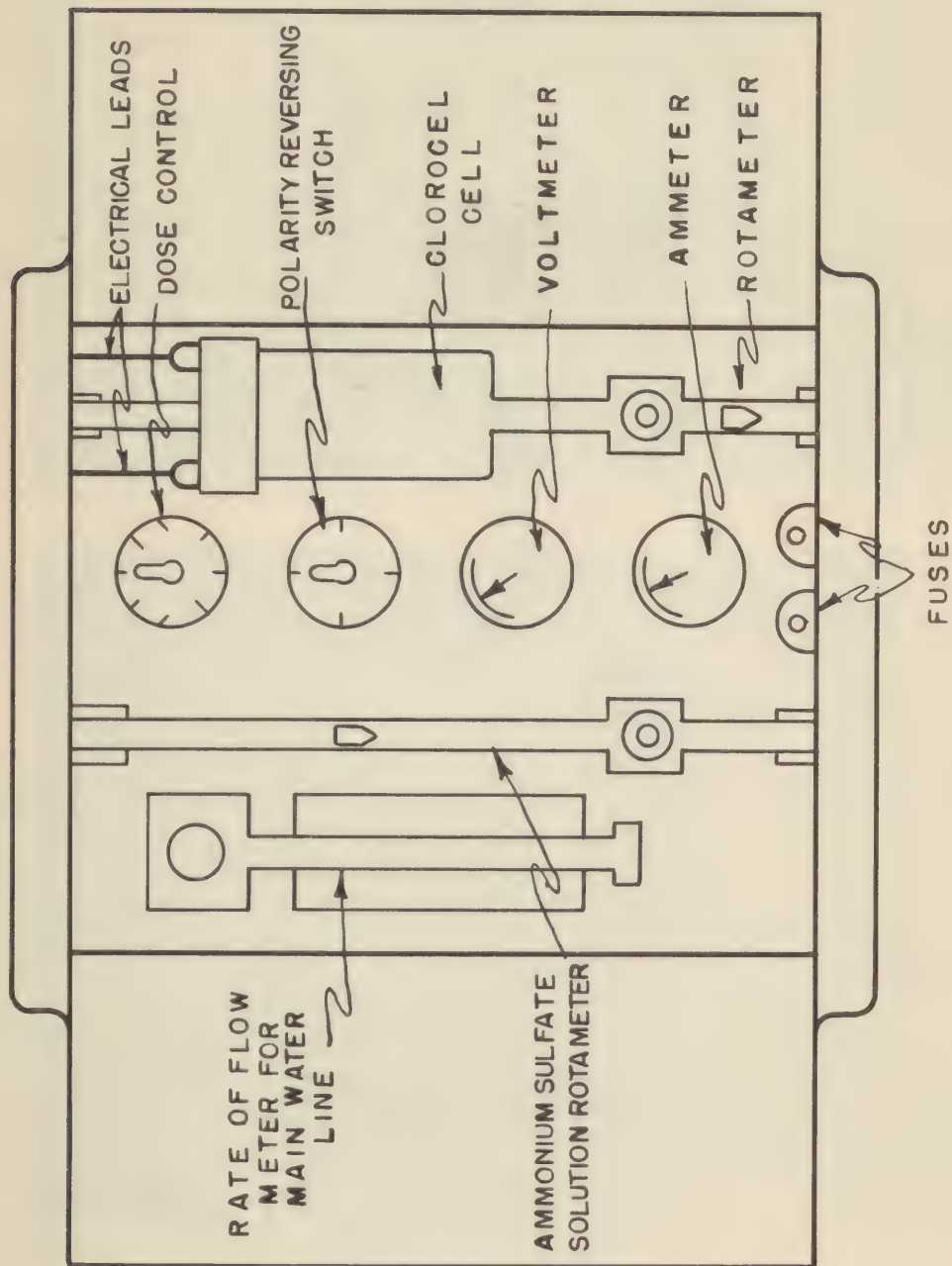
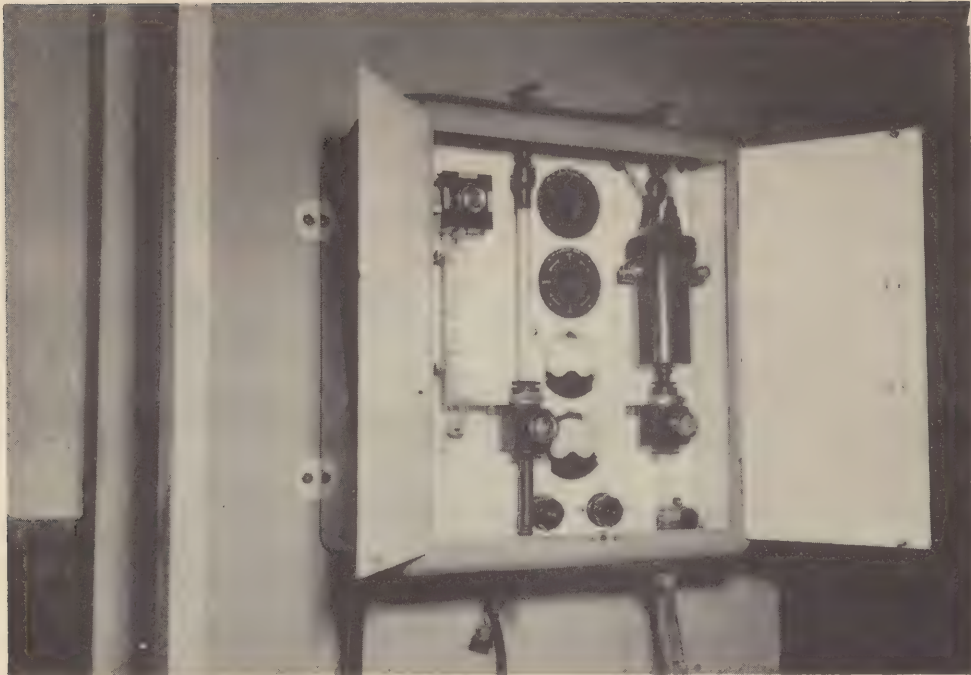


Fig. 1. Clorocel Steriliser, manufactured by The Paterson Engineering Company, Limited, London, W. C. 2, England.



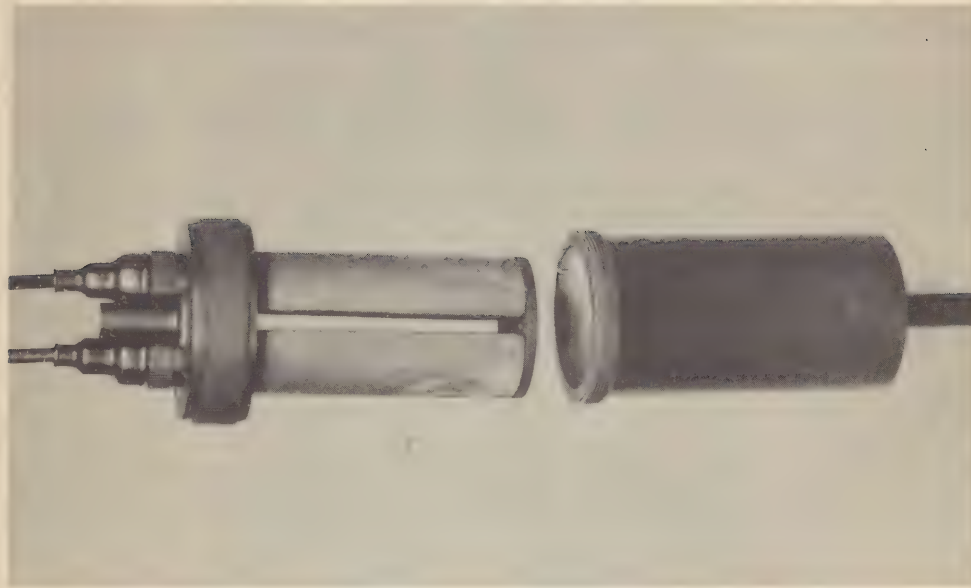
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Fig. 2. Clorocel Steriliser mounted on wall. Top: cabinet open, showing hypochlorite cell and operating panel. Bottom: cabinet closed.





190-3-18  
Fig. 3. Clorocel assembled.

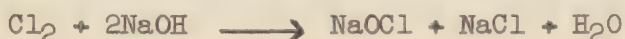


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Fig. 4. Clorocel with electrodes removed  
from case.

portion of the chlorination is done by each of the two methods is not known.

## II. INVESTIGATION

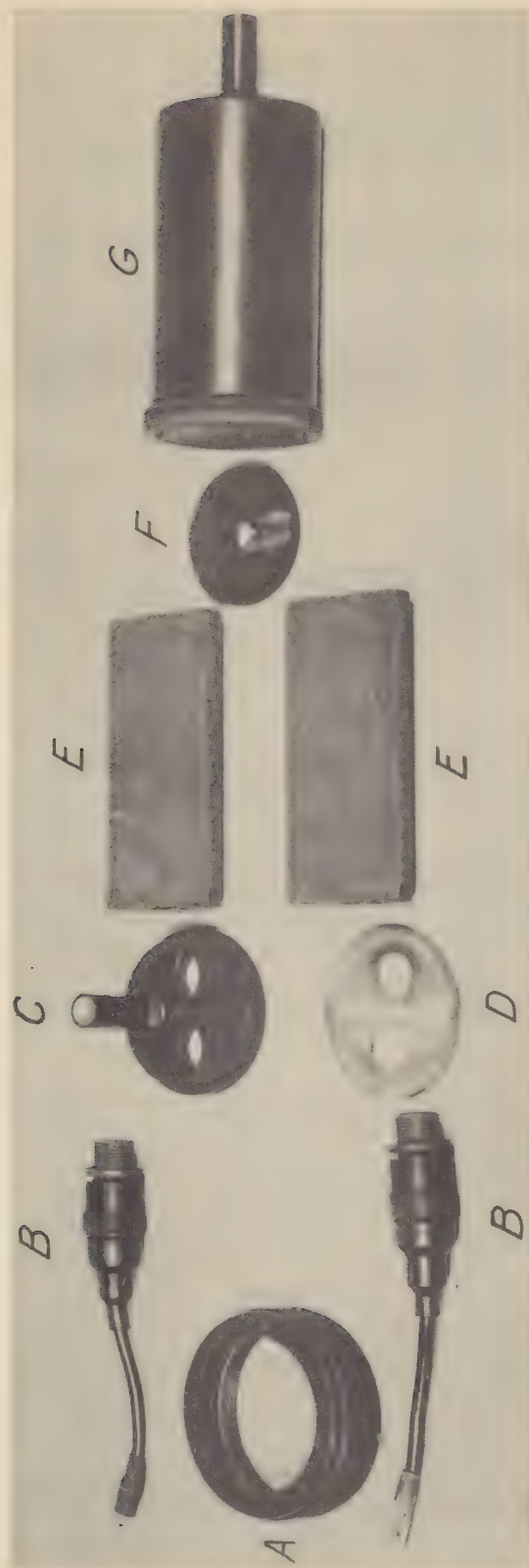
7. General. The Clorocel Steriliser (electrolytic sodium hypochlorite unit) is produced by the Paterson Engineering Company, Limited, Kingsway, London, W. C. 2, England, and is distributed in this country by Infilco Company, Incorporated, Chicago, Illinois. This unit was obtained on loan for test purposes from Infilco. The heart of the steriliser is a cell containing two carbon electrodes. A salt solution is passed through the cell with direct current (6 to 12 volts) flowing between the electrodes. Part of the salt is converted to chlorine and sodium hydroxide which combine immediately to form sodium hypochlorite ( $\text{NaOCl}$ ) as shown by the following equations:



Detailed theoretical aspects of the electrolysis of sodium chloride are given in Appendix C.

8. Equipment Tested. The Clorocel Steriliser, for which arrangements had previously been made for loan to the Navy for test, was given preliminary inspection by representatives of ERDL and the Office, Chief of Engineers, at the invitation of Infilco Company, Incorporated. This unit was the only one available in the United States. Only one cell, actually a spare part of the Clorocel Steriliser, was available for test purposes at the ERDL. This cell was forwarded to the Laboratories with the understanding that a rectifier and other auxiliary equipment would be needed to operate the cell in lieu of the complete unit. The spare cell and the auxiliary equipment are referred to throughout this report as the "Clorocel." Tests using this cell were begun during the summer of 1947. The Clorocel Steriliser, the complete commercial unit, was not obtained for test purposes until 7 January 1948. Prior to this time the unit had undergone laboratory tests at the Naval Medical Research Institute, Bethesda, Maryland. Results of this investigation are reported in "A Laboratory Investigation of Chlorocel, an Electrolytic Sodium Hypochlorite Producing Unit" by William V. Comsolazio and Hubert J. Mark, 30 July 1947 Project NM 011 014 Report No. 1. Since the cells for the two units are identical, all data arrived at with the Clorocel are believed to be the same as would have been obtained with the Clorocel Steriliser unit.





190-3-20  
 Fig. 5. Clorocel with component parts disassembled: A, screw cap; B, electrical leads; C, top cover and electrode holder; D, gasket; E, electrodes; F, electrode spacer plate; and G, cell casing.

a. Clorocel Steriliser. The steriliser is housed in an all metal cabinet,  $24\frac{1}{2}$  by 22 by 15 inches, and weighs approximately 200 pounds. The alternating current rectifier is inclosed in the rear of the cabinet. The hypochlorite cell and other items of equipment on the operating board are illustrated in Figs. 1 and 2.

The main flow meter and dosage control valve serve to regulate the chlorine dose when hypochlorite is being injected directly into a water line. The ammonium sulfate solution rotameter serves to measure the dose when ammonia is being fed directly into the line with the chlorine. Both items are features of the British commercial model and were not used during the tests made on the unit. The unit is identified by the following data on the name plate:

Type SM/60; for alternating current only; volts  
100/125, 200/250 amperes 5/25; cycles 50/60;  
British Patent Nos. 569294 and 13810/45; Pater-  
son Engineering Company, Limited, Kingsway,  
London, W. C. 2.

Details of construction of the hypochlorite cell are illustrated in Figs. 3, 4, and 5. The cell consists of a pair of carbon electrodes contained in a cylindrical plastic case. The electrodes, semicircular in cross section, are fitted into the case so that the curved surfaces rest against the inside surface of the case. The flat faces, which measure 6.20 by 2.93 inches, are held 0.11 inch apart by a template. The brine solution (10 percent sodium chloride is recommended by the manufacturer) flows through the cell from the bottom upward at the rate of 450 ml/min, passing between the flat faces in the process. This cell, rated to draw 60 amperes at 6 volts a-c, is the largest of the series manufactured by Paterson, 15- and 30-ampere cells being likewise available.

b. Clorocel. To test the spare cell obtained originally from the Infilco Company, a rectifier and other auxiliary equipment were assembled to make an operating unit. A schematic drawing and a photograph of this completed assembly are shown in Figs. 6 and 7, respectively. In operation, the brine feed solution flows by gravity from the constant level feed funnel through the rotameter and control valve into the bottom of the cell. The effluent from the cell discharges into a separator where the hydrogen formed in the electrolysis is removed and the syphon effect of the discharge hose is broken. A portable battery charger of the type used in garages and filling stations for the rapid charging of storage batteries, was used to provide the direct current for the cell. The charger, manufactured by Benwood Linze Company, St. Louis, Missouri, operated on 115 volts, 60 cycles a-c, only, and was fitted with fine and coarse ampere-hour controls, a voltage selector switch, and an



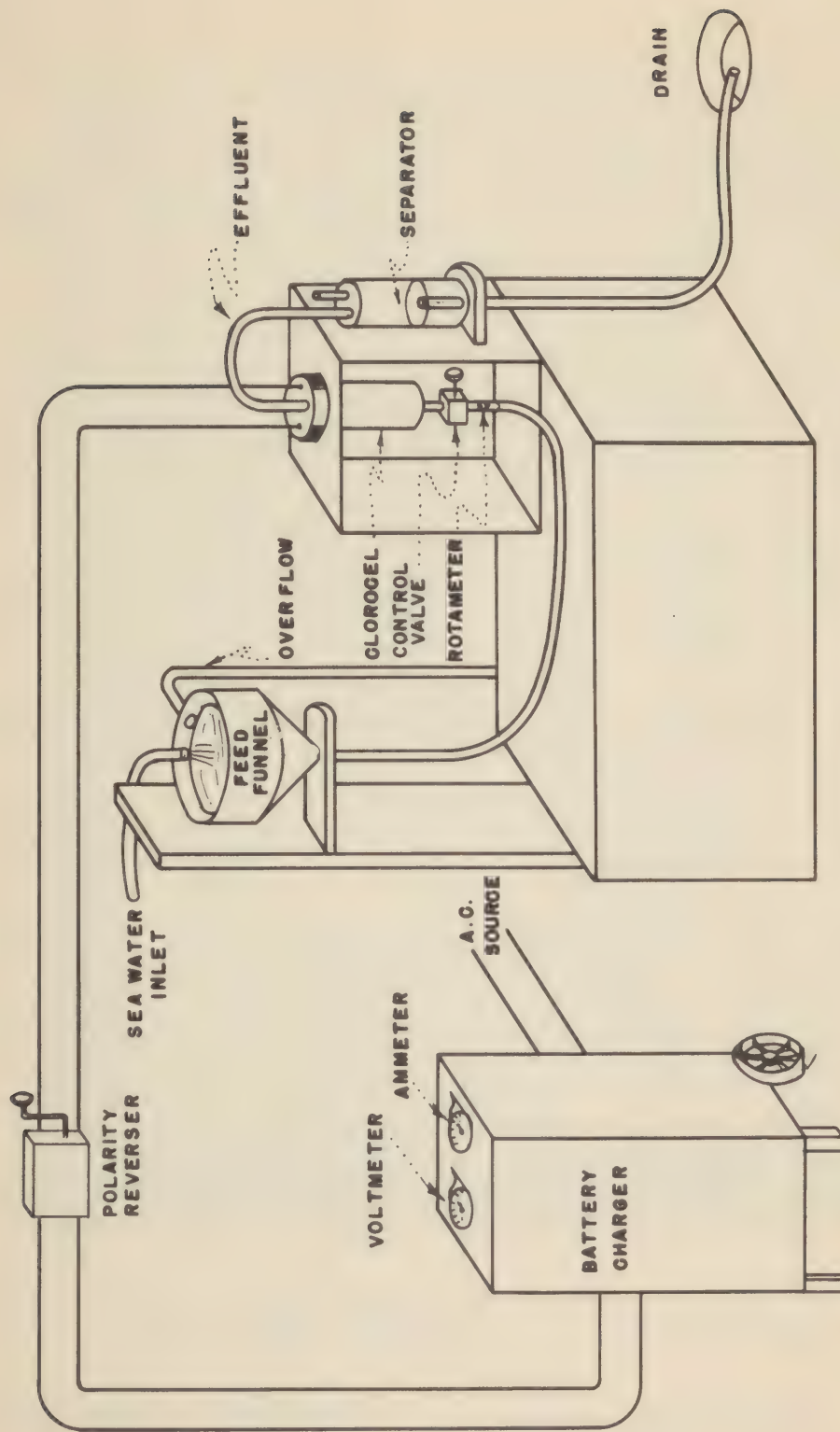


Fig. 6. Experimental Clorocel assembly (apparatus employed in sea water tests), Fort Story, Virginia.

ampere-hour indicator switch. An additional voltmeter and ammeter were placed on the unit to check the exact input to the cell. Polarity reversal was made by a Square D, double-throw switch.

c. Auto Generator As Current Source for Clorocel. As a special test, a Dodge weapons carrier having a 12-volt generator was used to furnish current for the Clorocel, and a Stewart-Warner electrical fuel pump was used to circulate the brine. Further details of the test assembly are given with the actual test data.

9. Objectives of Tests. The chief objectives of the test program were: (1) to determine the operating characteristics and durability of the cell under continuous operation over an extended period with sea water; and (2) to obtain general performance data needed to evaluate the operating characteristics of the cell under various conditions of brine feed.

10. Location of Tests. Preliminary laboratory tests were made at the ERDL, Fort Belvoir, Virginia. Durability tests on sea water and various other sea water tests were made at the ERDL Distillation Test Section, located directly on the Atlantic Ocean at Fort Story, Virginia.

11. Plan of Test. The following over-all plan was established for the investigation of the Clorocel equipment:

a. Preliminary Laboratory Tests. Preliminary laboratory tests (Appendix D) to be made at Fort Belvoir using the spare cell.

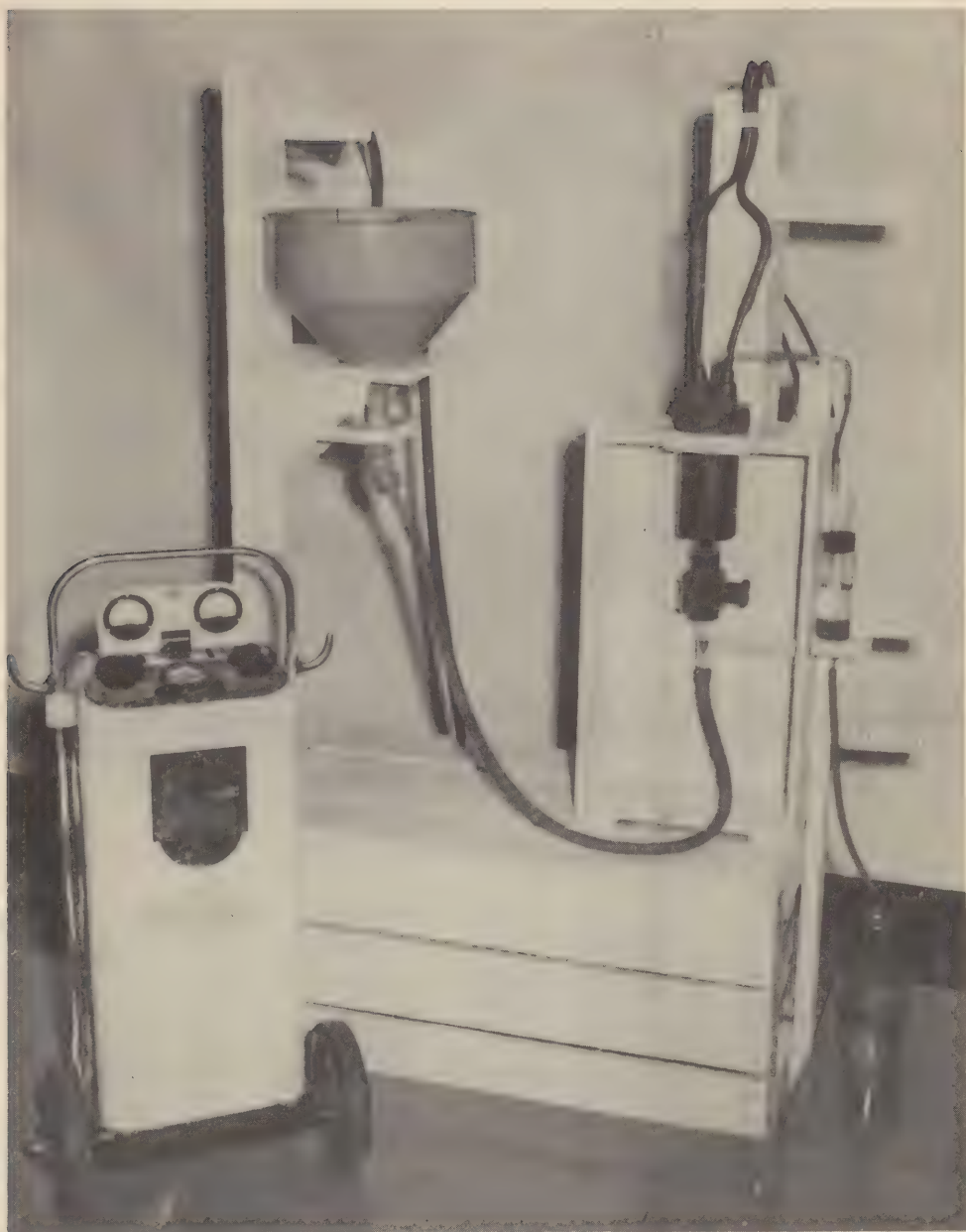
b. Special Performance Tests. General operating characteristics of the cell to be determined by short special tests. These tests to include effect of polarity reversal; rating of cell; effect of temperature, acidity, and iron impurities; recirculation to build up available chlorine; stability of effluent; and operation with pure salt solution as compared with sea water.

c. Durability Tests. Durability tests to be made to determine the life of electrodes, and their efficiency, when the Clorocel unit is operated continuously on sea water. Both Clorocel Steriliser and Clorocel to be operated serving as duplicate tests.

d. Clorocel Operated from Auto Generator. Tests to be made of the practicability of using the electrical system of a standard vehicle to furnish current for the cell.

12. Analytical Testing Methods. Analyses made on sea water during the tests included determination of alkalinity, chloride, pH, and available chlorine.





190-3-2  
Fig. 7. Clorocel assembly with principal components, battery charger, gravity feed tank, and electrolytic cell.

Alkalinity tests were made according to the standard methods for water examination using 0.02N  $\text{H}_2\text{SO}_4$  and titrating to the methyl orange endpoint. Results are expressed as ppm  $\text{CaCO}_3$ , the standard form for expressing alkalinity values.

Chloride determinations in sea water were made by titrating a 5-ml sample with 0.1N  $\text{AgNO}_3$  using potassium chromate as the indicator. Results are expressed as ppm chloride ion ( $\text{Cl}$ ). The chloride value should not be confused with the actual sodium chloride ( $\text{NaCl}$ ) concentration in the brine.

The pH of the brine solution was measured electrolytically using the glass electrode. A Macbeth line operated pH meter was employed.

Available chlorine concentrations were determined using the sodium thiosulfate titration. An aliquot of the hypochlorite solution was slightly acidified with 6N sulfuric acid, a solution of KI was added to react with the hypochlorite, and the liberated iodine equivalent to the available chlorine was titrated with the standard 0.1N  $\text{Na}_2\text{S}_2\text{O}_3$  solution using starch as the indicator. The available chlorine determined by the above-mentioned titration represents the oxidizing power of the solution expressed as an equivalent amount of chlorine. Some confusion may arise because the available chlorine is greater than the chlorine present in the sodium hypochlorite ( $\text{NaOCl}$ ) molecule. This is true because a molecule of  $\text{NaOCl}$  is equal to 2  $\text{Cl}$  ions in oxidizing power, as shown by the reaction of  $\text{NaOCl}$  with KI in the following equation:



13. Sea Water Analysis. Table I presents a comparison of the analyses of Fort Story and average sea waters.

14. Special Detail Tests with the Clorocel. The following series of special tests were made at Fort Story, Virginia:

a. Voltage, Amperage, Power, and Polarity Relationships with Sea Water. Table II shows the amperage and voltage relationships of the Clorocel near the beginning of the tests when the cell was new. The data are plotted as Fig. 8. It is seen that a comparatively large voltage is required before there is an appreciable current flow. A breakdown voltage of approximately 3 volts is required to start the transfer of electrons to and from the ions. It is also seen that once the breakdown voltage is passed, the voltage-amperage relationship is a straight line having the equation  $E = 0.139I + 3.1$ . The slope of this line increases as the cell wears out; that is, the resistance of the cell increases as the flat surfaces of the electrodes erode, giving a greater gap. This results in an increased voltage to maintain a given amperage.



Table I. Sea Water Analysis

Ingredient		Fort Story (mg/l)	Avg Sea Water (mg/l)
Calcium	Ca	301	400
Magnesium	Mg	954	1272
Sodium	Na	-	10556
Potassium	K	-	380
Chloride	Cl	13850	18980
Sulfate	SO <sub>4</sub>	1928	2650
Alkalinity	CaCO <sub>3</sub>	90	112
Bromide	Br	-	65
Boric Acid	H <sub>3</sub> BO <sub>3</sub>	-	26
R <sub>2</sub> O <sub>3</sub>		10	-
Silicious Matter		5	-
Solids on Evaporation		27033	-
pH		8.0	7.9 - 8.2

Note: Data are taken from H. U. Sverdrup, M. W. Johnson, and R. H. Fleming, The Oceans, Their Physics, Chemistry, and General Biology (New York: Prentice-Hall, Inc., 1946).

Table II. Amperage and Voltage Relationships  
for the Operation of the Clorocel

Battery Charger Setting		Influent Temper- ature (F)	Effluent Temper- ature (F)	Current (amp)	Voltage (v)	Power (kw)	Temper- ature Rise (F)
Coarse	Fine						
1	7	52.5	54.5	9.0	4.4	0.040	2.0
2	"	52.0	56.5	18.0	5.8	0.104	4.5
3	"	51.5	60.0	26.0	6.8	0.177	8.5
4	"	51.0	62.0	30.0	7.3	0.219	11.0
5	"	51.0	64.0	34.0	7.8	0.265	13.0
6	"	51.0	67.0	38.0	8.4	0.319	16.0
7	"	50.5	72.0	46.0	9.6	0.442	21.5
8	"	50.5	76.0	49.0	10.0	0.490	25.5

Note: Feed: Sea water, alkalinity 94.5 ppm, pH 7.7, chlorides 14,200 ppm (as Cl).

Feed Rate: Rotameter reading 450 ml/min, actual measured rate 465 ml/min.

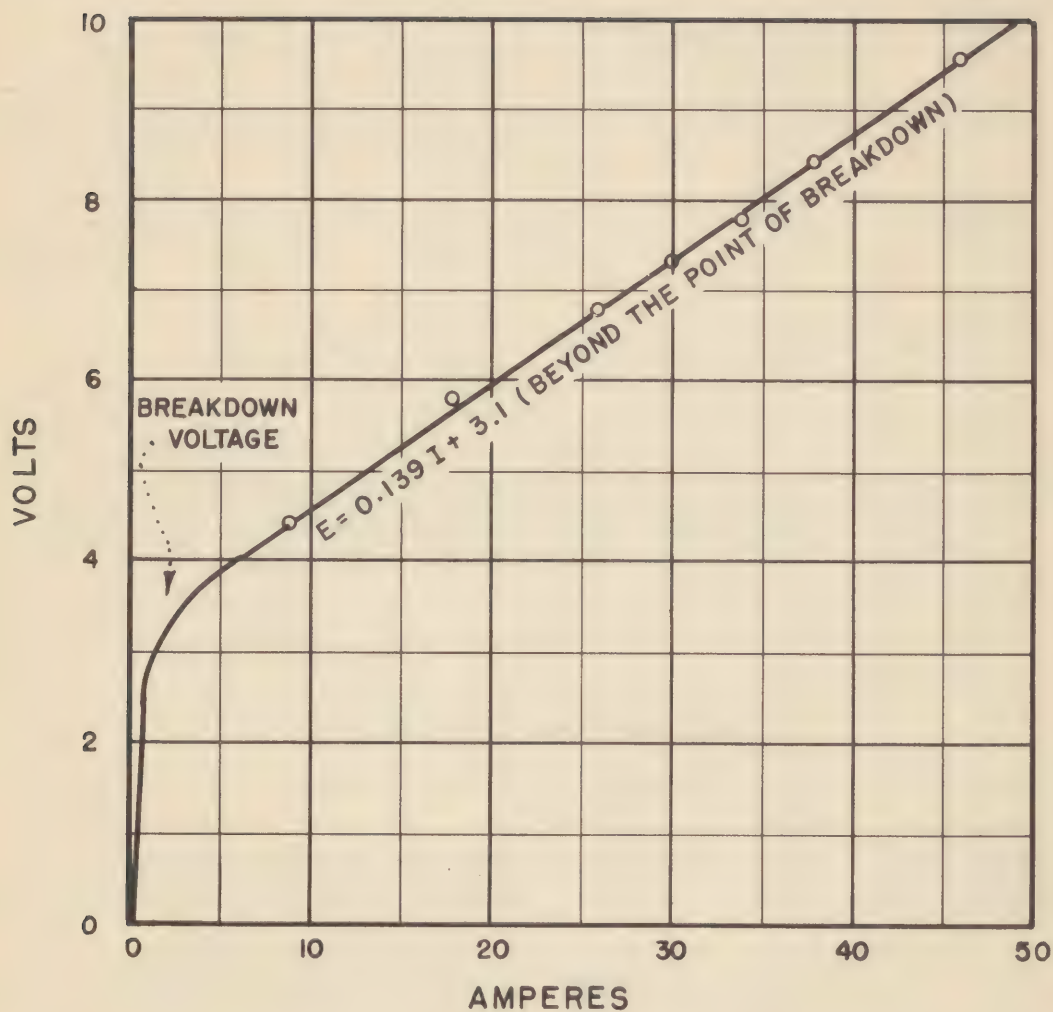


Fig. 8. Amperage and voltage relationships for operation of Chlorocel. Feed: Sea water, alkalinity 94.5 ppm, pH 7.7, chlorides 14,200 ppm (as Cl). Feed Rate: Rotameter reading 450 ml/min, actual measured rate 465 ml/min. Influent Temperature: 51.3 F (avg).



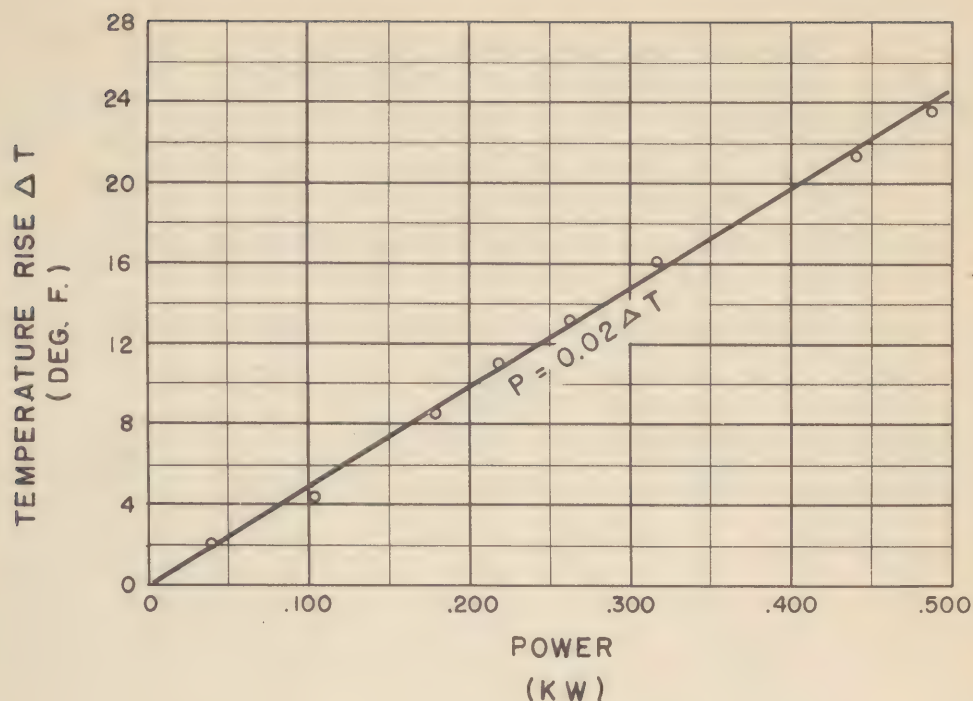


Fig. 9. Temperature rise vs power for operation of Clorocel. Feed: Sea water, alkalinity 94.5 ppm, pH 7.7, chlorides 14,200 ppm (as Cl). Feed Rate: Rotameter reading 450 ml/min, actual measured rate 465 ml/min. Influent Temperature: 51.3 F (avg).

In Fig. 9, temperature rise is plotted against power. It is seen that the plot is a straight line through the origin and the temperature rise is directly proportional to the power. Expressed mathematically:

$$P = K \Delta T$$

where

$P$  = power (kw)

$\Delta T$  = change in temperature (F)

$K$  = relation between power and temperature rise

The value of  $K$  is chiefly a function of flow rate. In the above-mentioned test, made at a flow rate of 465 ml/min, the equation becomes:

$$P = 0.02 \Delta T$$

Hence, 1 kw produces 50 F rise in temperature of the effluent.

Table III indicates the results of polarity reversal that is, the effects of sending the direct current in the opposite

direction. The data are plotted in Fig. 10. It is seen that the available chlorine concentration drops steadily at a given polarity. Then, when the polarity is reversed, the concentration drops to almost zero. Finally, the concentration returns to a value higher than it was before the polarity reversal.

Table III. Available Chlorine Concentration before and after a Single Polarity Reversal (Clorocel)

Accumulated Total Time of Sampling (sec)	Differential Time Periods for Collect- ing Effluent (sec)	Volume of Effluent Collected (ml)	Avail- able Chlorine (ppm)	Remarks
0				
60	60	460	757	Clear effluent
120	60	470	744	" "
120	Reversed Polarity			
130	10	96	224	Slight white gela- tinous precipitate in effluent
140	10	104	43	Considerable white gelatinous precipi- tate in effluent
150	10	95	592	Considerable white gelatinous precipi- tate in effluent
160	10	76	923	Clear effluent
170	10	86	985	" "
180	10	82	1008	" "
240	60	460	1025	" "
300	60	467	1008	" "
360	60	487	992	" "
420	60	452	945	" "

Note: Feed: Sea water, alkalinity 94.5 ppm, pH 7.6, chlorides 13,900 ppm (as Cl).

Feed Rate: Rotameter reading 450 ml/min.

Current: 46 amperes.

Voltage: 8.4 volts.



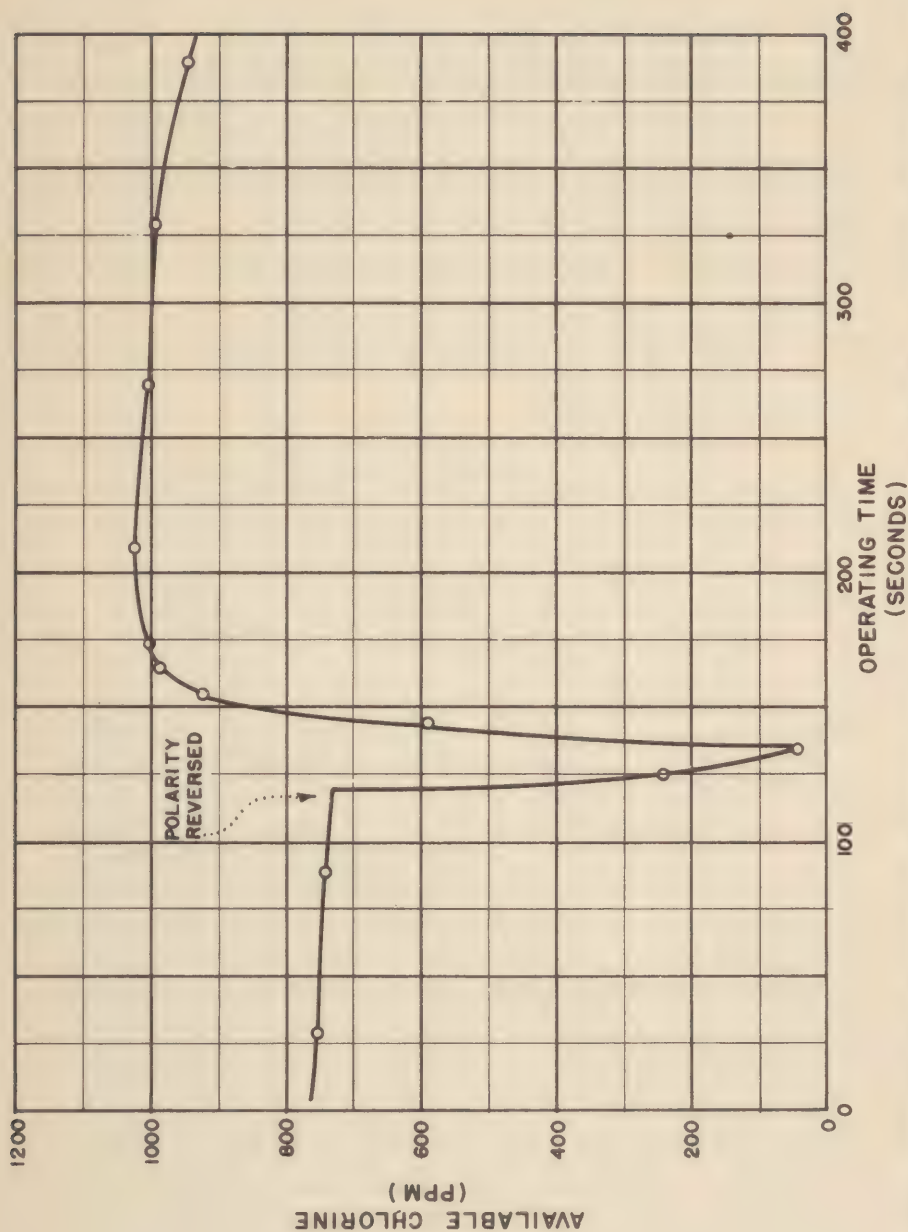


Fig. 10. Available chlorine concentration before and after a single polarity reversal (Clorocel). Feed: Sea water, alkalinity 94.5 ppm, pH 7.6, chlorides 13,900 ppm (as Cl). Feed Rate: Rotameter reading 450 ml/min. Influent Temperature: 54 F. Current: 46 amperes. Voltage: 8.4 volts. Note that the operating time is plotted as mid-points of sample collecting periods.

Table IV. Drop in Available Chlorine  
at a Constant Polarity (Clorocel)

Elapsed Time (hr) (min)		Polarity	Current (amp)	Available Chlorine (ppm)	Remarks
0	0	plus	40	610	Polarity reversed immediately after sampling
-	1	minus	40	1080	
-	5	"	40	1080	
-	30	"	40	976	
1	-	"	40	890	
2	-	"	40	716	
3	-	"	40	602	
4	-	"	40	526	
5	-	"	40	478	
6	-	"	40	457	
7	-	"	40	446	
8	-	"	40	444	
9	-	"	40	457	Polarity reversed immediately after sampling
9	5	plus	41	970	

Note: Feed: Sea water, alkalinity 94.0 ppm, pH 8.6, chlorides 14,250 ppm (as Cl).

Feed Rate: Rotameter reading 450 ml/min, actual measured rate 425 ml/min.

Influent Temperature: 35.4 F (avg).

Battery Charger Setting: 8 coarse, 7 fine.

Voltage: 10.5 volts.



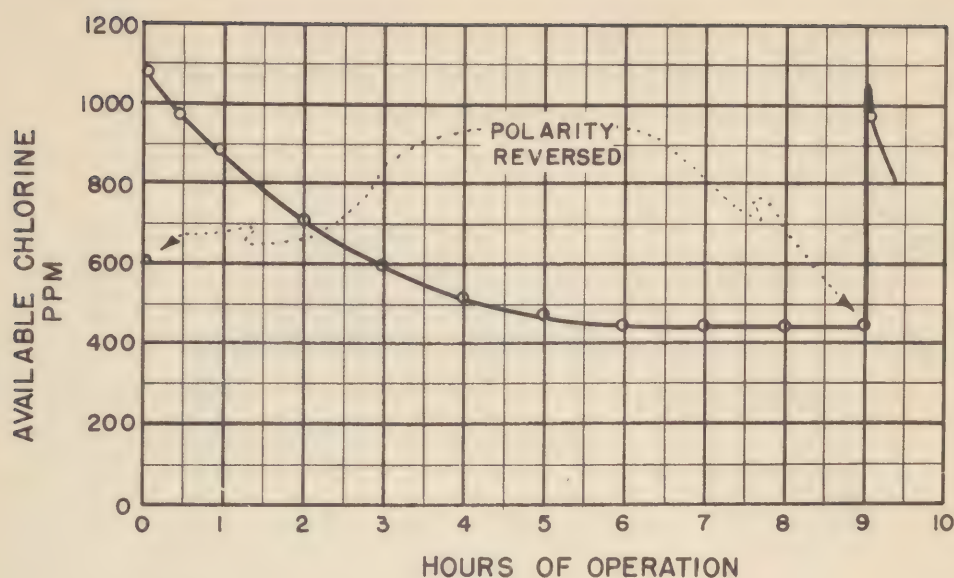


Fig. 11. Drop in available chlorine at a constant polarity (Clorocel). Feed: Sea water, alkalinity 94.0 ppm, pH 8.6, chlorides 14,250 ppm (as Cl). Feed Rate: Rotameter reading 450 ml/min, actual measured rate 425 ml/min. Influent Temperature: 35.4 F (avg). Current: 40 amperes. Voltage: 10.5 volts.

b. Drop in Available Chlorine Output at a Constant Polarity with Sea Water. Table IV shows the magnitude of the available chlorine concentration drop when the Clorocel is run for many hours at the same polarity. The data are plotted in Fig. 11. It is seen that, at an amperage of 40 and at a flow rate of 425 ml/min, the available chlorine in the effluent is about 1100 ppm immediately after the polarity is reversed. This concentration drops to about 450 ppm in 5 hours and thereafter does not drop any more. The question then arose as to whether this concentration drop was a result of the presence of impurities in the sea water, that is, of salts other than sodium chloride. It was believed that magnesium hydroxide scale or precipitation of some kind might inhibit the formation of sodium hypochlorite. In order to test this theory, the cell was cleaned thoroughly and a run was made with USP sodium chloride dissolved in distilled water at a concentration of 14,250 ppm, the same as that of the sea water at Fort Story. The results are shown in Table V and the data are plotted in Fig. 12. It is seen that there is a definite drop in available chlorine at a constant polarity even with pure sodium chloride and distilled water. The above-described test demonstrates that the impurities in the sea water are not alone responsible for the drop in available chlorine output following polarity reversal, and that normal electrochemical reactions occurring during electrolysis account for a large part of the drop. To overcome the effect of

Table V. Operation of the Clorocel Using USP Sodium Chloride Dissolved in Distilled Water to a Chloride Concentration of 14,250 ppm

Elapsed Time		Polarity	Current (amp)	Available Chlorine (ppm)	Available Chlorine Calculated to 40 Amperes (ppm)	Remarks
(hr)	(min)					
0	0	plus	41	-	-	Polarity reversed
-	5	minus	40	1023	1023	
-	30	"	40	782	782	
1	-	"	40	665	665	Polarity reversed immediately after sampling
1	5	plus	41	1090	1065	
1	30	"	41	826	806	
2	-	"	41	716	700	

Note: Cell: Cleaned thoroughly before test.  
 Feed: USP NaCl dissolved in distilled water to a chloride concentration of 14,250 ppm.  
 Feed Rate: Rotameter reading 450 ml/min, actual measured rate 455 ml/min.  
 Influent Temperature: 49.0 F (avg).  
 Battery Charger Setting: 7 coarse, 7 fine.  
 Current: 40 amperes (avg).  
 Voltage: 9.8 volts (avg).

this condition of polarization, reversal of current flow or mechanical agitation is normally used.

c. Polarity Reversal with 10 Percent Sodium Chloride Solution. The recommended feed solution for the Paterson Clorocel is a 10 percent sodium chloride brine, and consequently, although the tests made with the unit were primarily with sea water, a run was made with this solution to check the output of the cell and to provide data for comparison, as shown in Table VI. It is seen that with a 10 percent NaCl brine the amperage was about 60 at a voltage of 8.5. In a comparable test, with sea water having the same



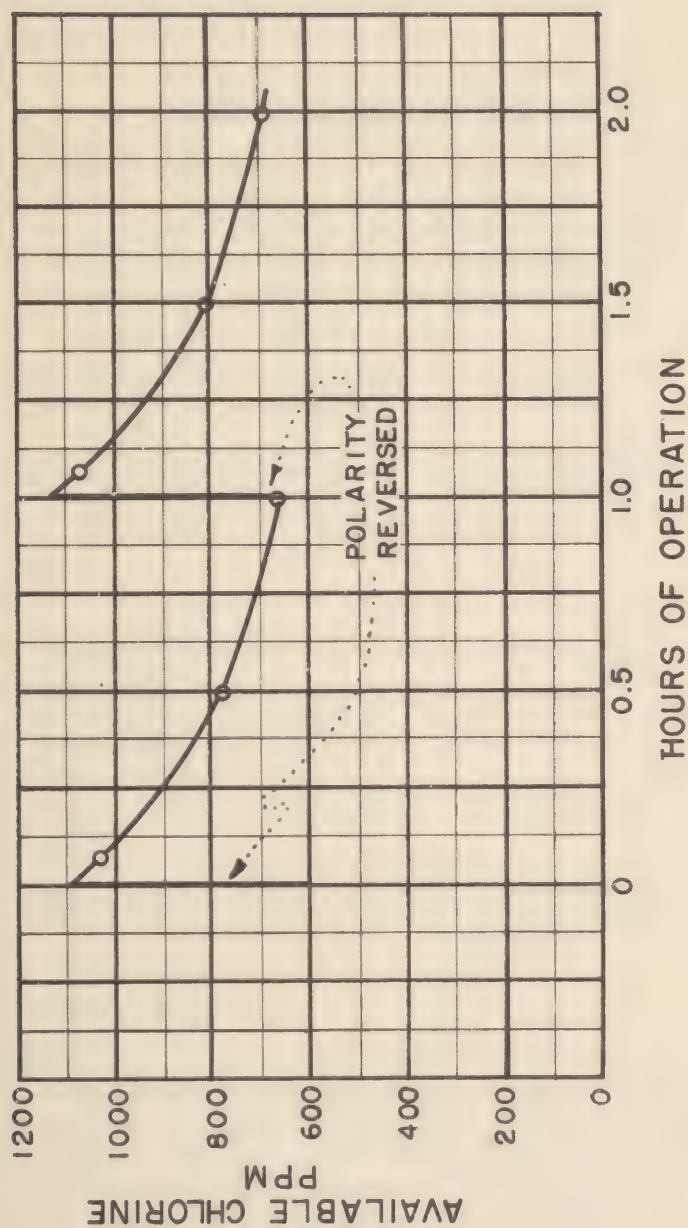


Fig. 12. Operation of Clorocel using USP sodium chloride dissolved in distilled water to a chloride concentration of 14,250 ppm. Cell: Cleaned thoroughly before test. Feed: USP NaCl dissolved in distilled water to a chloride concentration of 14,250 ppm. Feed Rate: Rotameter reading 450 ml/min, actual measured rate 455 ml/min. Influent Temperature: 49.0 F (avg). Current: 40 amperes (avg). Voltage: 9.8 volts (avg).

Table VI. Clorocel Operated with 10 Percent NaCl Solution

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Elapsed Time (hr) (min)	Polarity	Influent Temperature (F)	Effluent Temperature (F)	Actual Measured Feed Rate (ml/min)	Current (amp)	Voltage (v)	Available Chlorine (ppm)
0	plus	41	68	420	61.0	8.5	2790
30	"	42	69	420	61.0	8.5	2735
	reversed						
35	minus	41	69	420	63.0	8.5	2595
1 -	"	42	67	425	62.0	8.5	2580
1 30	"	42	68	425	63.0	8.5	2595
	reversed						
1 35	plus	42	70	425	65.0	8.5	2625
2 -	"	43	70	425	61.0	8.5	2650
2 30	"	44	71	425	61.0	8.5	2615

Note: Feed: Common salt dissolved in tap water to 10 percent strength.

Feed Rate: Rotameter reading 450 ml/min.

Battery Charger Setting: 7 coarse, 1 fine.



temperature as the salt brine, and with the cell having about the same total operating life, the amperage was 40 at a voltage of 10.5. With a flow rate of 425 ml/min the 10 percent NaCl solution produced an effluent with 2650 ppm available chlorine.

It is interesting to note that the concentration did not drop at a constant polarity as is characteristic for solutions of low salt concentrations.

d. Initial Operating Characteristics of Clorocel with Sea Water. It was expected that the performance of the cell would change after operation over an extended period. Since various special tests on sea water were contemplated, in which a comparison with the original performance would be needed, a special test was made at the beginning of the program when the cell was comparatively new, and had been operated for only a few hours on laboratory tests. In this test, its average output, current efficiency, and cell economy were determined. The results are shown in Table VII. The current efficiency is defined as follows:

$$\text{Current efficiency} = \frac{\text{Grams of available chlorine produced per hour} \times 100}{\text{Grams of available chlorine which should be produced per hour by Faraday's law}}$$

Example:

Grams available chlorine per hour	- - - -	22.4
Amperage	- - - - -	36.7
Atomic weight chlorine	- - - - -	35.5
Conversion factor	- - - - -	96,500 coulombs

releases 1 gram atomic weight of Cl

$$\begin{aligned} \text{Current efficiency} &= \frac{(22.4) (100)}{(36.7) (3600) (35.5)} \\ &= 46.2\% \end{aligned}$$

The available chlorine production per hour is plotted against both amperage and power in Fig. 13. It was decided to establish 40 amperes as the standard amperage with sea water, and to accept whatever voltage was necessary to maintain this amperage, the voltage depending on the resistance of the cell which, in turn, is a function of temperature, brine concentration, and the gap between the electrodes. The resulting watt input to the cell with sea water at 40 amperes and 8.9 volts corresponds closely to the watt input to the cell when operated on a 10 percent NaCl solution at 60 amperes

Table VII. Operating Characteristics of the Clorocel

Run No.	Battery Charger Setting	Coarse	Fine	Duration of Run (hr)	Effluent Volume (l)	Influent Temperature (F)	Effluent Temperature (F)	Available Chlorine (ppm)	Available Chlorine (gm/hr)	Current (amp)	Voltage (v)	Power (kw)	Theoretical Available Chlorine (gm/hr)*	Current Efficiency (%)	Cell Economy (gm Available Chlorine per kw-hr)	Conversion of Chloride in Sea Water to Available Chlorine (%)
1	1	7		2	54.6	49.0	50.9	173	4.7	10.4	4.4	0.046	13.8	34.2	102.0	1.2
2	3	7		2	53.7	49.2	58.1	594	15.9	27.2	6.8	0.186	36.0	44.3	85.5	4.2
3	6	7		2	53.7	44.6	59.3	834	22.4	36.7	8.4	0.308	48.6	46.2	72.7	5.9
4	8	7		2	54.0	47.0	72.5	1128	30.4	50.0	10.0	0.500	66.2	45.9	60.8	7.9

\* By Faraday's Law. 96,500 coulombs release 1 gram - equivalent (35.5 gm) of chlorine.

Note: Feed: Sea water, alkalinity 94.5 ppm, pH 7.7, chlorides 14,200 ppm (as Cl).

Feed Rate: Rotameter reading 450 ml/min.

Polarity: Reversed hourly.

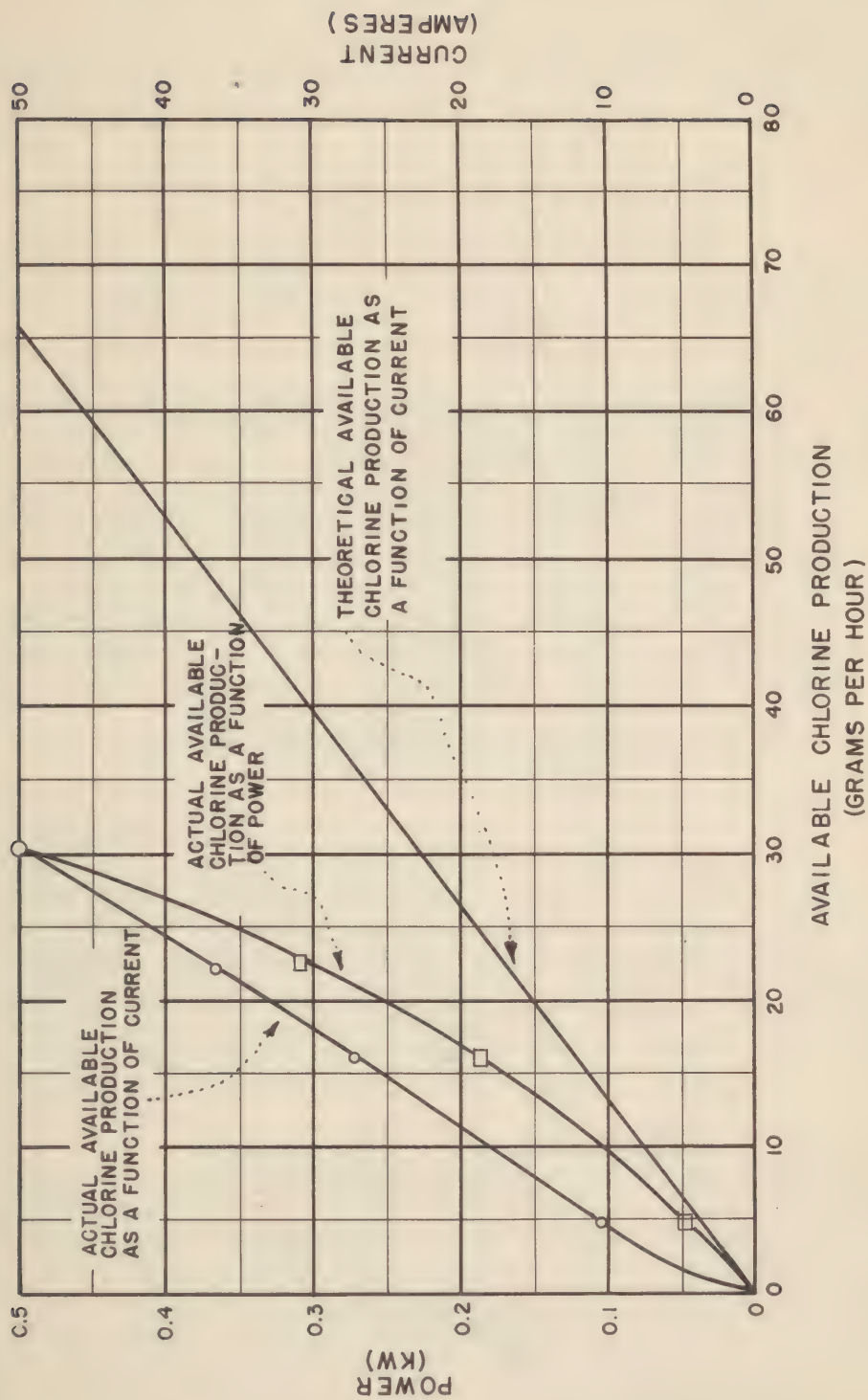


Fig. 13. Operating characteristics curves for Chlorcel. Feed: Sea water, alkalinity 94.5 ppm, pH 7.7, chlorides 14,200 ppm (as Cl). Feed Rate: Rotameter reading 450 ml/min. Influent Temperature: 47.2 F. Polarity: Reversed hourly.



and 6 volts. Operating characteristics of a new cell using sea water are tabulated as follows:

Chloride in sea water (ppm) - - - - -	14,200
Amperage - - - - -	40
Voltage - - - - -	8.9

(at an influent temperature of 47 F and with new electrodes)

Available chlorine output (gm/hr) - - - - -	24
Polarity - - - - -	Reversed hourly
Current efficiency (%) - - - - -	45
Cell economy (gm available chlorine per kw/hr) - - - - -	68

e. Effect of Acidity on Output with Sea Water. In order to determine the effect of acidulated sea water upon the output of the Clorocel, runs were made with sea waters having 94, 51, and 12 ppm alkalinity and 26 ppm acidity, respectively. The results are given in Table VIII. It was found that, although a lower alkalinity resulted in a reduced output of available chlorine, the reduction was comparatively small. The greatest reduction in output, obtained with a feed of 26 ppm acidity, was only 12 percent. Variation in the alkalinity of the sea water appears to be a negligible factor in the operation of the Clorocel.

Table VIII. Effect of Acidulated Sea Water  
on the Operation of the Clorocel

Run	Sea Water Alka- linity (ppm)	Feed (pH)	Current (amp)	Voltage (v)	Actual Measured		Available Chlorine Calculated to 40 Amperes (gm/hr)
					Feed Rate (ml/min)	Available Chlorine (ppm)	
1	94.0	8.6	37.5	9.8	430	778	21.4
2	51.0	7.6	38.0	10.0	435	724	19.9
3	11.8	6.4	38.0	10.0	440	686	19.1
4	-26.4	4.0	38.5	10.0	440	689	18.9

Note: Feed: Sea water, chlorides 14,250 ppm (as Cl), avg temperature 35.5 F.

Feed Rate: Rotameter reading 450 ml/min.

Polarity: Reversed hourly.

Acid used for Acidulation: Nitre cake.

f. Effect of Temperature on Output with Sea Water. In order to determine the effect of temperature upon the output of the Clorocel, runs were made with sea water at the following temperatures: 33, 67, 86, and 107 F. The results are given in Table IX. It was found that temperature has very little effect upon the available chlorine output of the Clorocel over the above-mentioned range.

Table IX. Effect of Temperature  
on the Operation of the Clorocel

Run	Average Influent Temperature (F)	Current (amp)	Voltage (v)	Actual Measured Feed Rate (ml/min)	Available Chlorine (ppm)	Available Chlorine Calculated to 40 Amperes (gm/hr)
5	33.0	40.5	10.4	430	806	20.6
6	66.5	43.5	9.1	490	800	21.6
7	85.5	39.0	8.1	520	692	22.2
8	106.5	39.0	7.6	533	610	20.0

Note: Feed: Sea water, alkalinity 94.0 ppm, pH 8.6, chlorides 14,250 ppm (as Cl).

Feed Rate: Rotameter reading 450 ml/min.

Polarity: Reversed hourly.

g. Effect of Dissolved Iron on Output with Sea Water. To determine the effect of dissolved iron upon the output of the Clorocel, a run was made with 100 ppm of Fe (dissolved as  $\text{FeCl}_3$ ) in sea water. This concentration of iron is greater than would ever be expected in normal sea water. A control run was made under identical conditions, but without iron. The results are shown in Table X. It was found that 100 ppm of dissolved iron reduced the available chlorine output of the Clorocel by 11 percent.

h. Recirculating to Increase Available Chlorine Concentration. Recirculation of the salt brine makes possible conversion of a larger percentage of the NaCl in the brine to hypochlorite. On a single pass through the Clorocel only a comparatively small percentage (approximately 4 percent) of the sodium chloride is converted to sodium hypochlorite. A large percentage of the salt passes unchanged into the water being chlorinated, and is wasted. Increasing the percentage of NaCl converted to hypochlorite has the following advantages: (1) the weight of sodium chloride that must be transported is reduced (this is not particularly important

Table X. Effect of Dissolved Iron on the Output of the Clorocel

	Control	Test Run
Iron Content (ppm)	0	100
Influent Temperature (F)	31.7	36.2
Influent pH	7.8	4.6
Actual Measured Feed Rate (ml/min)	415	377
Voltage (v)	10.5	10.3
Current (amp)	38.7	39.5
Available Chlorine (ppm)	721	724
Available Chlorine Calculated to 40 Amperes (gm/hr)	18.6	16.6

Note: Feed: Sea water, chlorides 14,000 ppm (as Cl).  
 Feed Rate: Rotameter reading 450 ml/min.  
 Polarity: Reversed hourly.

in places in which salt is available locally, but is a factor to be considered if salt is to be transported a considerable distance); and (2) the concentration of chloride ion in the treated drinking water is reduced.

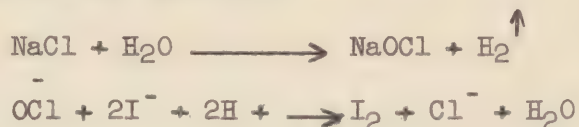
The effluent hypochlorite solution from the Clorocel produces 30 to 50 ppm NaCl for each part per million of available chlorine. In normal waters the chlorine content is low enough so that the additional NaCl added with the hypochlorite from the Clorocel during chlorination does not produce objectionable chloride concentrations. However, objectionable amounts of chloride could result in a special situation, especially when the normal chlorides are already high. For example, if superchlorination or break point chlorination were practiced using a dosage of from 10 to 20 ppm, such treatment would result in the addition of from 500 to 1000 ppm of sodium chloride in the treated water. If five times as great a concentration of available chlorine were produced in the cell product by recirculation, then the added sodium chloride in the treated water in the above-stated case would be reduced to 100 and 200 ppm NaCl, respectively.

If every molecule of NaCl were converted to NaOCl in the electrolysis, 121 pounds of available chlorine would theoretically be produced per 100 pounds of NaCl. In practice, no such production is ever achieved. The following equations show the calculation of the theoretical yield:





in Fig. 14. It is seen that, in ten passes, the available chlorine concentration rose to 7800 ppm, which is equivalent to 3900 ppm as chloride ion. Since the original sea water contained 14,250 ppm chloride ion, 10,350 ppm chloride ion remained unconverted to hypochlorite. The above calculation is based on the following reactions:



A stability test was made on the final effluent. The results are discussed below under subpar. 14i, "Stability of Product." The data are given in Table XII and are plotted in Fig. 15.

Table XII. Stability of Sodium Hypochlorite Solution  
Prepared by Ten Passes of Sea Water through the Clorocel  
(see Table XI)

Age of Solution (hr)	Available Chlorine (ppm)
0	7800
1	7690
9	7500
31	7360
59	7220
87	7020
157	6740
374	5650
706	4550

(2) Sodium Chloride Brine Treated by Repeated Passes through Clorocel. The tests were continued on a more comprehensive basis with a solution of common table salt in tap water. The desired solution was first made up in a porcelain pail and poured into the feed funnel. The solution then was allowed to pass through the Clorocel into another pail. The effluent was again poured back into the feed funnel and continued for as many as twenty passes. In order to obtain a maximum yield, the polarity was reversed every 10 minutes, the battery charger was maintained at its maximum output position, and a cooling coil was installed directly after the Clorocel to minimize undesirable side reactions. Runs were made with 0.62, 1.24, 2.44, and 4.76 percent sodium chloride solutions. Readings were made on each pass for influent temperature, effluent temperature, amperage, voltage, flow rate, and available chlorine

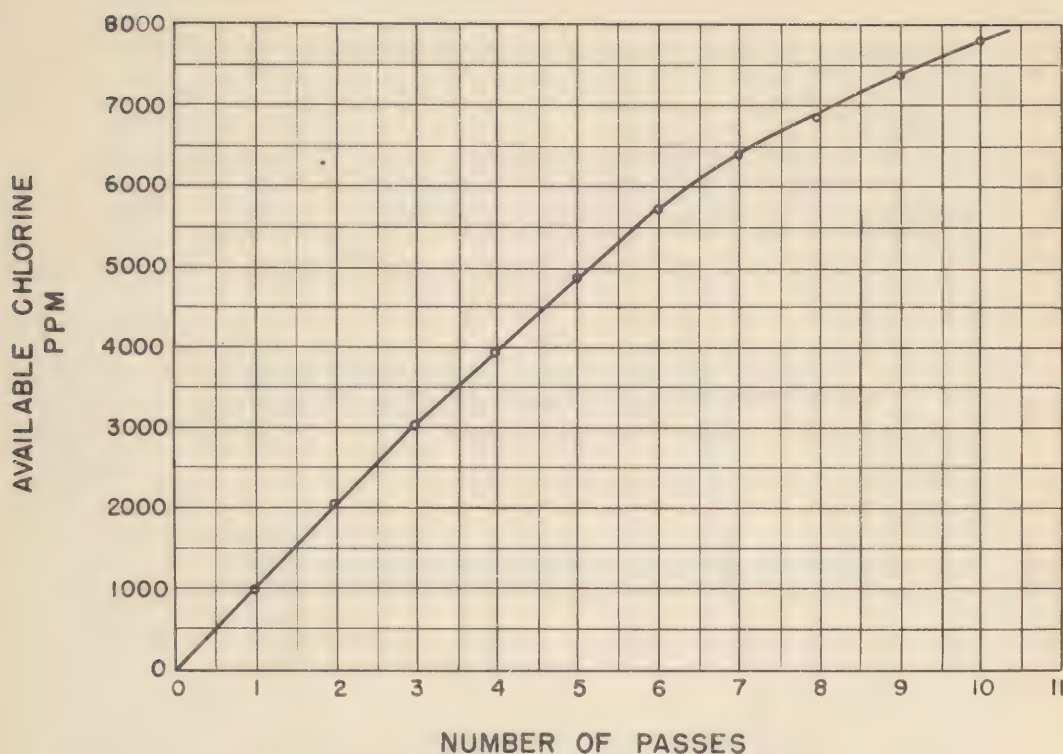


Fig. 14. Increasing sodium hypochlorite concentration in sea water by repeated passes through Clorocel. Feed: Sea water, first pass alkalinity 94.0 ppm, pH 8.6, chlorides 14,250 ppm (as Cl). Feed Rate: Rotameter reading 450 ml/min. Current: 48.2 amperes (avg). Voltage: 9.65 volts (avg). Polarity: Reversed every 10 min.

concentration. A cooling coil was employed in each test except for a duplicate run with the 0.62 percent NaCl, in which case the cooling coil was omitted to ascertain the extent of temperature rise. The results are shown in Tables XIII through XVIII. As a typical run, the data of Table XIII (0.62 percent NaCl solution) are plotted in Fig. 16. It is seen that the concentration of available chlorine rose steadily until about the tenth pass. It then leveled off and began to drop about the fifteenth pass. Beyond the fifteenth pass the rate of decomposition of the sodium hypochlorite was greater than the rate of its formation. During the first five passes nearly an equal amount of available chlorine is produced for the high point of each succeeding pass indicating uniform electrical efficiency over this range. The curve, at the thirteenth pass, showed 1390 ppm of available chlorine. This gave a yield of 22.2 pounds of available chlorine per 100 pounds of NaCl. The yield was computed in similar fashion for the other three runs, 1.24, 2.44, and 4.76



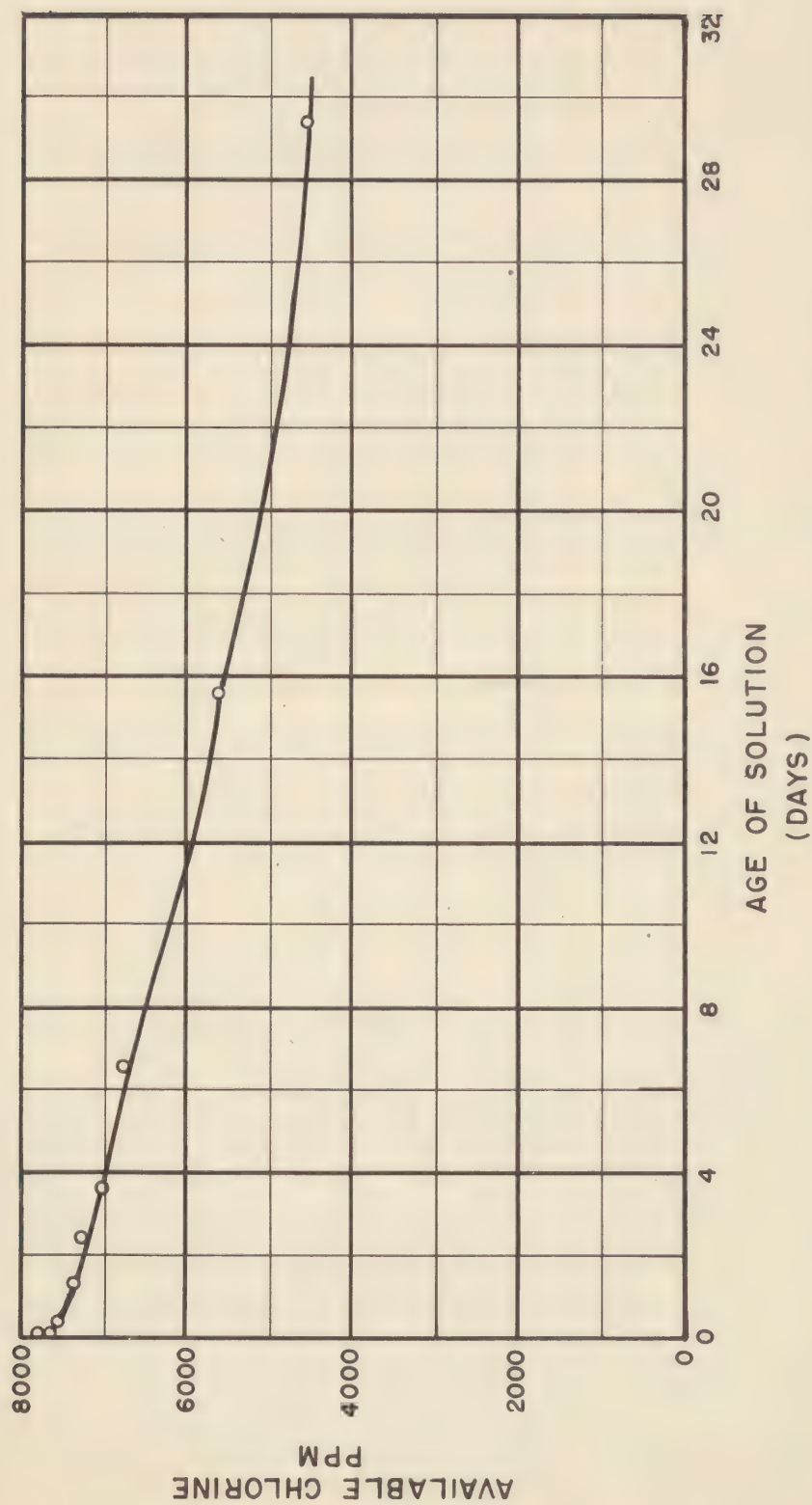


Fig. 15. Stability of sodium hypochlorite solution prepared by ten passes of sea water through Clorocel.

Table XIII. Repeated Passing of 0.62 Percent NaCl Solution through the Clorocel without the Cooling Coil

Pass	Time Started	Influent Temperature (F)	Effluent Temperature (F)	Current (amp)	Voltage (v)	Actual Measured Feed Rate (ml/min)	Available Chlorine in Effluent (ppm)
1	0850	52	71	38.0	10.8	470	298
2	0908	67	86	39.0	10.8	510	595
3	0924	80	98	39.0	10.7	520	805
4	0939	88	106	41.0	10.6	525	1042
5	0954	97	114	41.0	10.7	530	1155
6	1010	102	120	42.0	10.6	535	1290
7	1025	108	124	42.0	10.6	550	1348
8	1039	110	126	42.0	10.6	550	1382
9	1053	113	130	42.0	10.6	550	1382
10	1107	114	132	42.0	10.6	555	1382
11	1121	114	132	42.0	10.6	550	1382
12	1135	119	134	40.0	10.6	550	1348
13	1148	119	135	38.0	10.7	550	1330
14	1202	119	136	42.0	10.8	550	1295
15	1215	122	138	41.0	10.7	545	1260
16	1228	122	138	38.0	10.8	550	1242
17	1241	122	139	38.0	10.8	555	1190
18	1254	123	140	40.0	10.8	555	1172
19	1307	123	140	40.0	10.8	555	1140
20	1320	121	139	41.0	10.6	570	1104
		avg 106.8	avg 123.9	avg 40.4	avg 10.69	avg 541	

Note: Feed: First pass, 8 liters tap water, 50 grams common table salt.  
 Feed Rate: Rotameter reading 450 ml/min.  
 Battery Charger Setting: maximum, 8 coarse, 7 fine.  
 Polarity: Reversed every 10 min.  
 Ambient Temperature: 60 F.

Table XIV. Repeated Passing of 0.62 Percent NaCl Solution  
through the Clorocel with the Cooling Coil

Pass	Time Started	Influent Temperature (F)	Effluent Temperature (F)	Current (amp)	Voltage (v)	Actual Measured Feed Rate (ml/min)	Available Chlorine in Effluent (ppm)
1	1025	58	77	35.0	10.8	510	210
2	1041	64	84	35.0	10.8	530	507
3	1058	68	86	34.0	10.9	530	672
4	1114	69	87	35.0	10.9	535	858
5	1129	68	87	35.0	10.9	510	980
6	1146	68	86	35.0	10.9	525	1120
7	1202	68	86	35.0	10.8	535	1172
8	1218	68	87	35.0	10.9	530	1260
9	1233	70	88	35.0	10.9	520	1330
10	1249	71	88	34.0	10.9	515	1330
11	1305	69	86	34.0	10.9	520	1372
12	1321	69	87	34.0	10.9	520	1382
13	1336	71	88	34.0	10.9	500	1390
14	1352	69	87	31.0	11.0	520	1382
15	1407	68	86	31.0	11.0	515	1365
16	1423	67	85	31.0	11.0	525	1302
17	1438	67	85	31.0	11.0	530	1268
18	1453	67	84	31.0	11.0	510	1250
19	1509	68	85	31.0	11.0	515	1220
20	1524	68	84	31.0	11.0	515	1145
		avg 67.8	avg 85.7	avg 33.4	avg 10.92	avg 521	

Note: Feed: First pass, 8 liters tap water, 50 grams common table salt.

Feed Rate: Rotameter reading 450 ml/min.

Battery Charger Setting: maximum, 8 coarse, 7 fine.

Polarity: Reversed every 10 min.

Ambient Temperature: 61 F.



Table XV. Repeated Passing of 1.24 Percent NaCl Solution through the Clorocel with the Cooling Coil

Pass	Time Started	Influent Temperature (F)	Effluent Temperature (F)	Current (amp)	Voltage (v)	Actual Measured Feed Rate (ml/min)	Available Chlorine in Effluent (ppm)
1	0900	58	82	46.0	10.1	505	883
2	0916	65	88	52.0	10.2	515	1670
3	0931	68	90	48.0	10.2	505	2390
4	0946	69	92	48.0	10.2	515	2940
5	1002	69	92	47.0	10.2	505	3390
6	1017	70	92	47.0	10.2	530	3680
7	1032	70	92	47.0	10.3	505	3870
8	1047	70	92	47.0	10.3	520	4050
9	1102	71	93	45.0	10.3	500	4190
10	1116	70	93	45.0	10.4	515	4320
11	1131	70	93	45.0	10.4	500	4325
12	1146	71	93	45.0	10.5	500	4360
13	1200	72	94	45.0	10.5	520	4370
14	1215	72	94	43.0	10.5	520	4340
15	1229	72	94	41.0	10.5	550	4250
		avg 69.1	avg 91.6	avg 46.1	avg 10.32	avg 514	

Note: Feed: First pass, 8 liters tap water, 100 grams common table salt.

Feed Rate: Rotameter reading 450 ml/min.

Battery Charger Setting: Maximum, 8 coarse, 7 fine.

Polarity: Reversed every 10 min.

Ambient Temperature: 73 F.

Table XVI. Repeated Passing of 2.44 Percent NaCl Solution  
through the Clorocel with the Cooling Coil

Pass	Time Started	Influent Temperature (F)	Effluent Temperature (F)	Current (amp)	Voltage (v)	Actual Measured Feed Rate (ml/min)	Available Chlorine in Effluent (ppm)
1	0900	56	84	56.0	9.9	505	1820
2	0918	63	90	60.0	9.8	505	3360
3	0934	68	95	60.0	9.8	520	4530
4	0950	69	96	61.0	9.9	510	5540
5	1007	68	95	62.0	9.9	520	6310
6	1023	69	96	60.0	10.0	520	7040
7	1038	70	98	60.0	9.9	520	7600
8	1054	71	98	61.0	9.9	560	8020
9	1110	71	99	60.0	10.0	515	8480
10	1125	69	98	61.0	10.0	510	8770
11	1141	68	96	59.0	10.0	520	8920
12	1156	68	96	59.0	10.0	525	9170
13	1212	68	96	59.0	10.0	520	9380
14	1227	68	96	57.0	10.0	520	9310
15	1242	68	96	57.0	10.0	525	9460
16	1258	66	94	57.0	10.0	525	9550
17	1313	66	94	56.0	10.0	520	9600
18	1328	66	94	59.0	10.0	540	9600
		avg 67.3	avg 95.1	avg 59.1	avg 9.95	avg 521	

Note: Feed: First pass, 8 liters tap water, 200 grams common table salt.

Feed Rate: Rotameter reading 450 ml/min.

Battery Charger Setting: Maximum, 8 coarse, 7 fine.

Polarity: Reversed every 10 min.

Ambient Temperature: 74 F.

Table XVII. Repeated Passing of 4.76 Percent NaCl Solution  
through the Clorocel with the Cooling Coil

Pass	Started	Influent Temperature (F)	Effluent Temperature (F)	Current (amp)	Voltage (v)	Actual Measured Feed Rate (ml/min)	Available Chlorine in Effluent (ppm)
1	0900	58	89	73.0	9.5	470	2685
2	0918	69	100	77.0	9.2	490	4940
3	0934	74	104	75.0	9.3	500	6760
4	0950	74	105	78.0	9.3	500	8340
5	1007	72	105	80.0	9.3	510	9600
6	1023	72	104	75.0	9.3	515	10800
7	1039	71	104	78.0	9.3	510	11750
8	1055	72	105	75.0	9.3	510	12490
9	1112	72	104	75.0	9.3	510	13250
10	1127	73	105	77.0	9.3	515	13800
11	1142	74	106	77.0	9.3	515	14200
12	1157	74	106	80.0	9.3	515	14680
13	1212	74	106	75.0	9.3	515	14980
14	1227	74	106	79.0	9.3	510	15200
15	1241	75	107	76.0	9.3	500	15500
16	1255	75	107	73.0	9.3	490	15600
17	1309	75	108	79.0	9.3	490	15800
18	1322	76	108	75.0	9.3	490	15980
19	1335	76	107	73.0	9.3	500	16150
20	1348	76	107	74.0	9.3	500	16280
		avg 72.9	avg 104.7	avg 76.2	avg 9.30	avg 503	

Note: Feed: First pass, 8 liters tap water, 400 grams common table salt.  
 Feed Rate: Rotameter reading 450 ml/min.  
 Battery Charger Setting: Maximum, 8 coarse, 7 fine.  
 Polarity: Reversed every 10 min.  
 Ambient Temperature: 72 F.



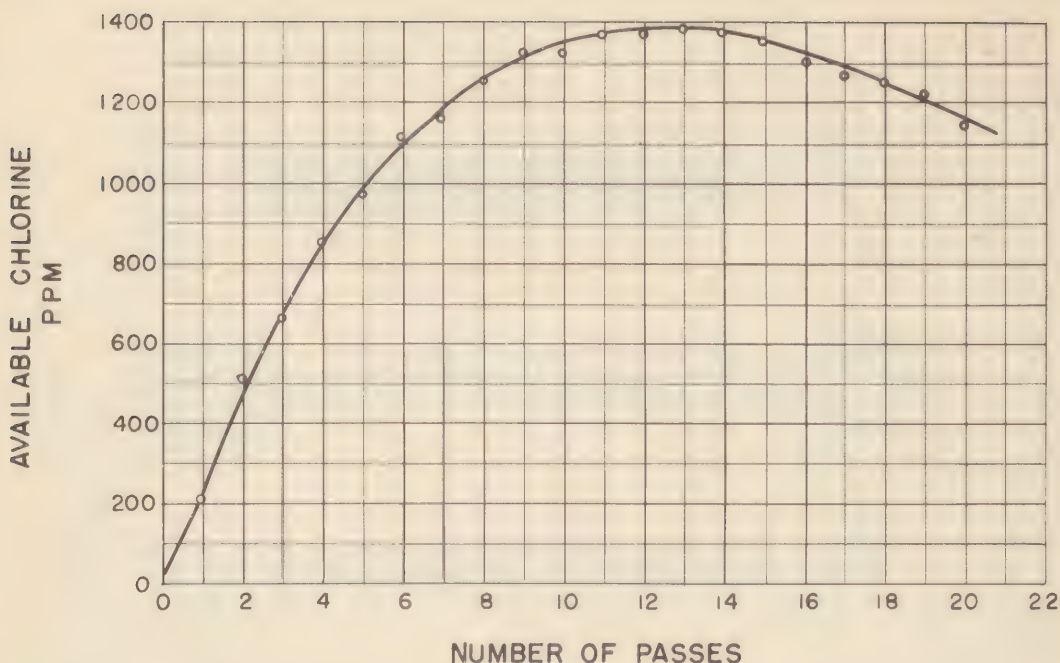


Fig. 16. Repeated passing of 0.62 percent NaCl solution through Clorocel. Cooling Coil: Present. Feed: First pass, 8 liters tap water, 50 grams common table salt. Feed Rate: Rotameter reading 450 ml/min, actual measured rate 521 ml/min (avg). Influent Temperature: 67.8 F (avg). Current: 33.4 amperes (avg). Voltage: 10.92 volts (avg). Polarity: Reversed every 10 min.

percent NaCl. These yields plus average temperatures, etc., for the four runs are shown in Table XVIII and the data are plotted in Fig. 17, from which it may seem that the optimum strength of sodium chloride solution is about  $2\frac{1}{2}$  percent. At this concentration a yield of about 39 pounds of available chlorine per 100 pounds of NaCl may be expected under more or less ideal conditions, that is, effluent cooled between passes and polarity reversed every 10 minutes.

(3) Continuous Recirculation of Sodium Chloride Brine. In order to determine the effect of recirculating through the Clorocel continuously, another run was made. The apparatus for this run is shown in Fig. 18. With this arrangement, the salt solution was put into the feed funnel and allowed to flow by gravity through the Clorocel. The effluent from the cell was then picked up by a Stewart-Warner 12-volt, electric-driven fuel pump and sent back into the feed funnel. Thus, there were no distinct passes as with the previous runs, but continuous recirculation. Length of time of operation replaced the number of passes as a

Table XVIII. Recapitulation of Runs to Build Up Concentration of Available Chlorine by Repeated Passes through the Clorocel with the Cooling Coil

Run	1	2	3	4
Common Salt (gm)	50	100	200	400
Tap Water (l)	8	8	8	8
NaCl (%)	0.621	1.24	2.44	4.76
No. of Passes	20	15	18	20
Avg Influent Temperature (F)	67.8	69.1	67.3	72.9
Avg Effluent Temperature (F)	85.7	91.6	95.1	104.7
Avg Current (amp)	33.4	46.1	59.1	76.2
Avg Voltage (volts)	10.92	10.32	9.95	9.30
Avg Actual Measured Feed Rate (ml/min)	521	514	521	503
Available Chlorine Concentration after Last Pass (ppm)	1145	4250	9600	16280
No. of Passes to Reach Maximum Concentration	13	13	18	20
Maximum Available Chlorine Concentration (ppm)	1390	4370	9600	16280
Yield (lb available chlorine per 100 lb NaCl)	22.2	35.0	38.6	33.2

Note: Feed Rate: Rotameter reading, 450 ml/min.  
 Battery Charger Setting: Maximum, 8 coarse, 7 fine.  
 Polarity: Reversed every 10 min.

criterion of performance. The data for this run are shown in Table XIX. A 2.44 percent NaCl solution was used and the Clorocel was operated continuously for 7 hours. The polarity was reversed hourly. A cooling coil cooled with tap water was in the system between the Clorocel and the pump. Hourly readings were made of the temperature of the effluent in the funnel, the temperature of the cooling water, the amperage, the voltage, and the available chlorine concentration. It is seen from the data in this table that a maximum available chlorine concentration of 8280 ppm was reached after 5 hours. This corresponds to a yield of 33.3 pounds of available chlorine per 100 pounds of NaCl. It should be noted that during the first hour the available chlorine concentration increases at a constant rate, indicating uniform electrical efficiency over this range.

A continuous recirculation of sodium chloride brine was also employed in a later test using the Dodge weapons carrier as a source of current for the cell.

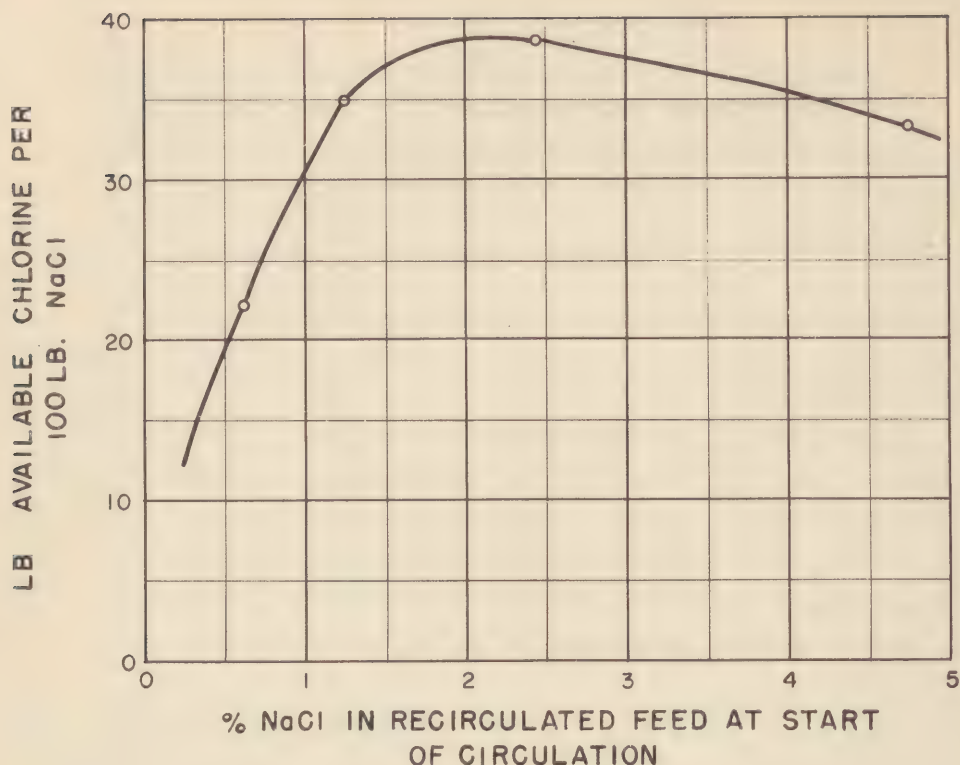


Fig. 17. Yield of available chlorine vs percentage of NaCl in recirculated feed at start of circulation. Note that highest point on this curve is indicative of highest yield obtained during course of making repeated passes of NaCl solution through Clorocel.

1. Stability of Clorocel Product. It is known that hypochlorites are unstable to a greater or lesser degree depending on whether they are in dry form or in water solution. In an earlier test, in which sea water was treated by repeated passes through the Clorocel, it was shown that a sodium hypochlorite solution prepared by passing sea water ten times through the Clorocel lost 42 percent of its strength by standing for one month in a stoppered glass container at room temperature. Data are given in Table XII and plotted in Fig. 15. Similar stability tests were made using sea water on effluents from single passes through the Clorocel. Data are given in Table XX and are plotted in Fig. 19. It is seen that the effluent directly after a polarity change is more stable than the effluent after a long period of time at the same polarity. This is shown as follows:

<u>Time of Sampling</u>	<u>Available Chlorine after 5 min Standing</u>	<u>Percentage of Drop in Concentration after 4 Days</u>
5 min after polarity change	953	32
65 min after polarity change	640	64



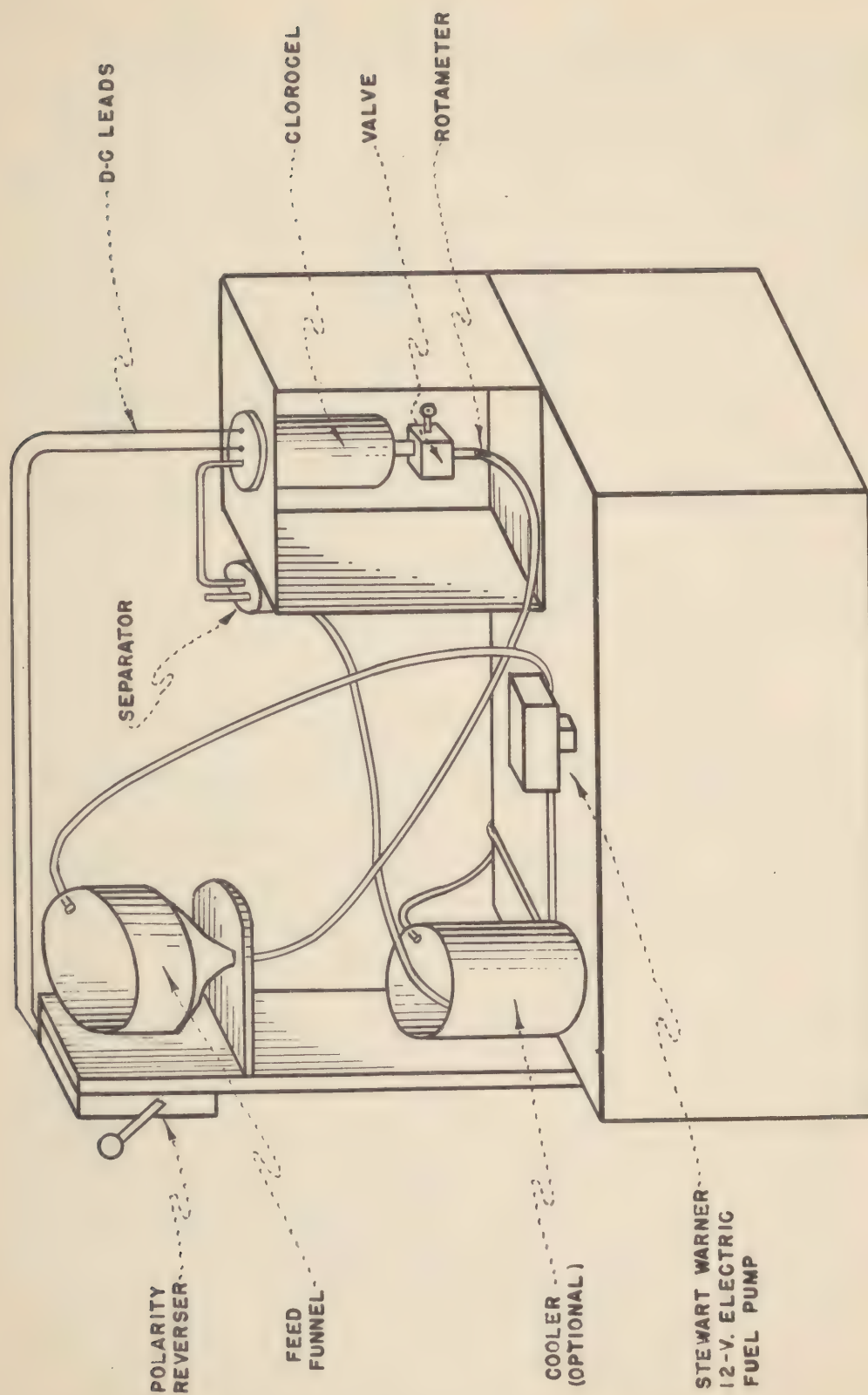


Fig. 18. Recirculation apparatus for Clorocel at Fort Story, Virginia.

Table XIX. Continuous Recirculation of 2.44 Percent NaCl Solution through the Clorocel with the Cooling Coil

Time of Operation (hr)	Temperature in Feed Funnel (F)	Temperature of Cooling Water (F)	Current (amp)	Voltage (v)	Available Chlorine Concentration (ppm)
0	58	59	55.0	10.0	0
1	63	61	56.0	10.0	3530
2	63	61	57.0	10.0	5900
3	63	61	57.0	10.0	7300
4	64	61	59.0	10.0	8070
5	65	61	57.0	10.0	8280
6	66	61	57.0	10.0	8280
7	66	61	57.0	10.0	8000

Note: Feed: At start, 8 liters tap water, 200 grams common table salt.

Feed Rate: Rotameter reading 450 ml/min.

Battery Charger: Maximum, 8 coarse, 7 fine.

Polarity: Reversed hourly.

Ambient Temperature: 69 F.

Table XX. Stability of Effluent from the Clorocel

Sample A - Taken 5 Min after Polarity Reversal				Sample B - Taken 65 Min after Polarity Reversal			
Influent Temperature: 32 F				Influent Temperature: 33 F			
Age of Solution			Available Chlorine	Age of Solution			Available Chlorine
(days)	(hr)	(min)	(ppm)	(days)	(hr)	(min)	(ppm)
-	-	5	953	-	1	5	640
-	2	-	940	-	2	-	602
-	4	-	935	-	4	-	556
1	-	-	879	1	-	-	349
2	-	-	815	1	-	-	262
5	-	-	750	5	-	-	229
8	-	-	686	8	-	-	218
14	-	-	650	14	-	-	217

Note: Feed: Sea water, alkalinity 91.1 ppm, pH 7.8, chlorides 14,000 ppm (as Cl).

Feed Rate: Rotameter reading 450 ml/min.

Actual Measured Feed Rate: 415 ml/min.

Battery Charger Setting: 8 coarse, 7 fine.

Current: 38 amperes.

Voltage: 10.5 volts.

Samples: Stored in stoppered glass bottles at room temperature.





15. Durability Tests. The durability tests described subsequently were made independently both with the Clorocel and the Clorocel Steriliser. The steriliser was used only for durability tests, all special tests having been made with the Clorocel.

a. Clorocel. In order to determine the durability of the electrolytic cell under continuous use, the Clorocel, when not being used for special tests, was operated continually. The operation time of the unit at Fort Story was distributed in the following order:

<u>Operation</u>	<u>Time Consumed (hr)</u>
Intermittent special tests	32
Continuous run (24-hr day)	197
Intermittent special tests	8
Continuous runs (24-hr day)	95
Intermittent special tests	50
Continuous run (24-hr day)	96
Intermittent special tests	3
Day shift operation	225
Total	<hr/> 706

Since only 8 hours of special testing separated the first two periods of continuous operation, they were combined as a single long run. This period covering 292 hours (12 days) is reported in detail as an example of continuous performance. During this continuous run of 24-hour days, the polarity was reversed every hour on the hour. Effluent samples were taken during the day shift on the half hour and analyzed for available chlorine. Readings were also made of the influent temperature, the effluent temperature, the amperage, the voltage, and the flow rate. All measurements were averaged and reported as such in Table XXI. Since the amperage varied somewhat from day to day, a final average was taken and individual daily chlorine output figures were adjusted to the final average. This adjustment was slight and perhaps unnecessary, but served to put each daily reading on a definite comparative basis. The adjusted daily outputs are plotted against time in Fig. 20. It is seen that, although there was some variation from day to day, the available chlorine production remained essentially constant. There was no downward trend such as would be the case if there were poisoning of the electrodes. The actual details of the shift operation are shown in Table XXII. In this test, samples were taken as usual during the day shift 1/2 hour after each polarity reversal. In addition, samples were taken immediately before and after reversal. The results, plotted in Fig. 21, show the effect of the polarity reversal on the available chlorine concentration. It is seen that the concentration dropped steadily during the hour's time following a polarity reversal but returned to a high value at the

Table XXI. Continuous Run of the Clorocel

Operating Time (days)	Influent Temperature (F)	Effluent Temperature (F)	Current (amp)	Voltage (v)	Actual Measured Feed Rate (ml/min)	Available Chlorine (ppm)*	Available Chlorine	
							Calculated to 41.8 Amperes (gm/hr)*	Cell Economy (gm available Chlorine per kw-hr)
0	54.0	71.9	8.3	46.1	485	989	26.1	74.8
1	52.3	71.0	8.5	44.9	460	963	24.8	69.7
2	48.4	67.0	8.5	41.5	425	975	25.1	70.2
3	48.6	67.9	8.5	41.6	410	974	24.2	67.2
4	53.1	73.9	8.6	44.0	390	1080	24.1	67.1
5	49.3	69.8	8.7	41.2	395	1066	25.6	70.1
6	48.7	73.3	8.8	41.1	328	1238	24.8	67.5
7	50.6	75.9	8.8	41.6	308	1336	24.8	67.6
8	49.0	73.3	8.7	40.5	331	1250	25.6	70.2
9	46.6	64.1	8.8	40.7	459	935	26.5	72.0
10	49.1	66.6	8.8	40.1	460	912	26.3	71.2
11	50.1	68.6	8.8	39.9	443	946	26.4	71.4
12	52.0	72.1	8.8	39.8	409	1002	25.8	70.5
	avg 50.1		8.7	41.8				

Note: Feed: Sea water, avg analysis, alkalinity 95.0 ppm, pH 8.0, chlorides 14,100 ppm (as Cl).  
 Feed Rate: Rotameter reading 450 ml/min.

Operation: 24-hr/day.

Polarity: Reversed hourly.

\* During the day shift, samples were taken for available chlorine analysis 1 - hour after polarity reversal. The sample values were averaged each day and adjusted to the 12-day average amperage of 41.8 for comparative purposes.

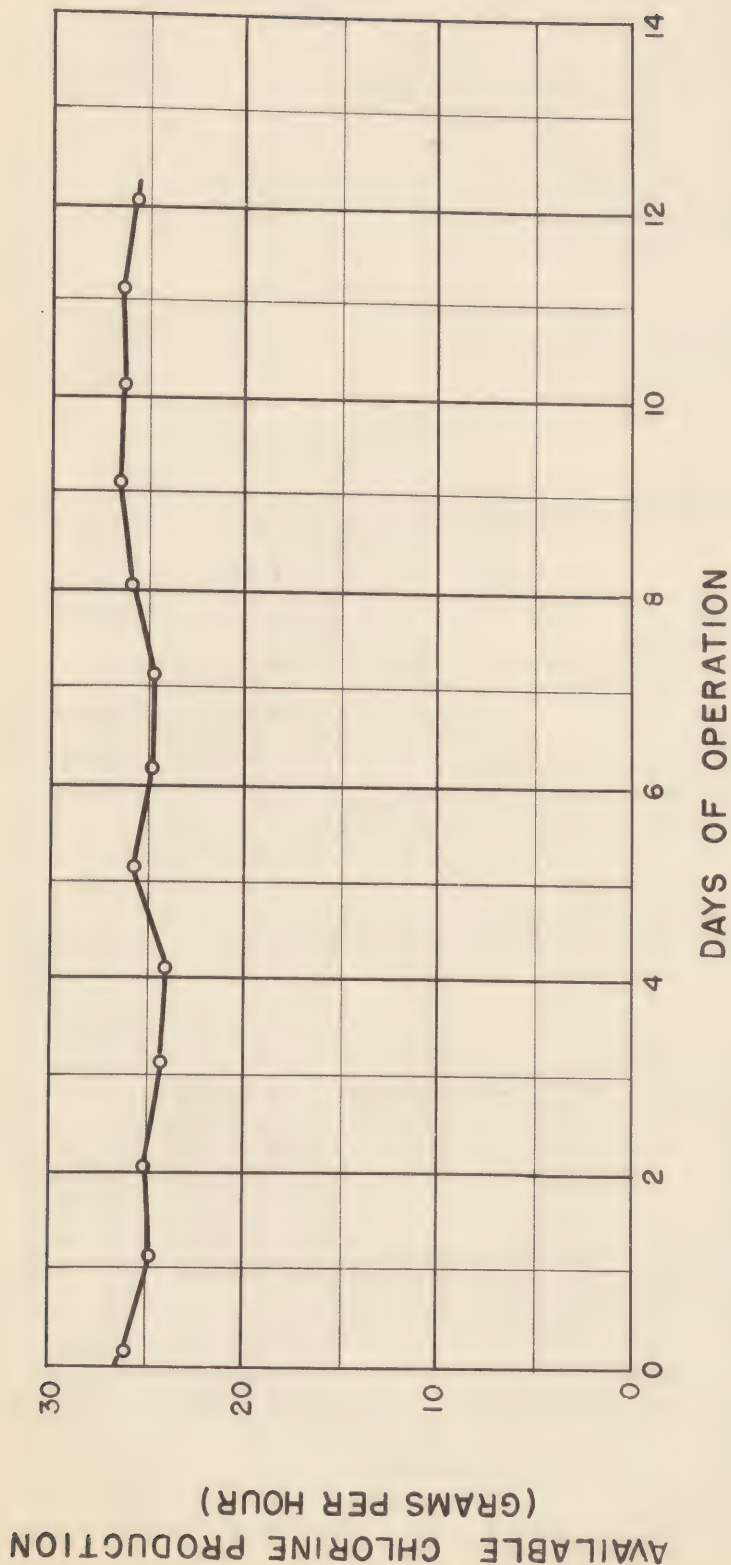


Fig. 20. Continuous run of Clorocel. Feed: Sea water, avg analysis, alkalinity 95.0 ppm, pH 8.0, chlorides 14,100 ppm (as Cl). Feed Rate: Rotameter reading 450 ml/min. Influent Temperature: 50 l F (avg). Current: 41.8 amperes (avg). Voltage: 8.68 volts (avg). Operation: 24-hr day. Polarity: Reversed hourly. During the day shift, samples were taken for available chlorine analysis  $\frac{1}{2}$  hour after polarity reversal. The sample values were averaged each day and adjusted to the 12-day average amperage of 41.8 for comparative purposes.



Table XXII. Typical Day's Operation of the Clorocel during Continuous Run

Time 11/19/47	Influent Temperature (F)	Effluent Temperature (F)	Current (amp)	Voltage (v)	Actual		Polarity
					Measured Feed Rate (ml/min)	Available Chlorine (ppm)	
0730	48	70	39.0	8.7	335	1013	Plus, reversed after sampling
0735	48	70	41.0	8.6	335	1275	Minus
0800	48	72	41.0	8.7	335	1205	"
0830	48	71	41.0	8.7	335	1110	" , reversed after sampling
0835	48	71	41.0	8.7	335	1232	Plus
0900	48	72	40.0	8.7	335	1165	"
0930	48	72	40.0	8.7	335	1089	" , reversed after sampling
0935	49	72	41.0	8.7	335	1314	Minus
1000	49	73	41.0	8.8	335	1219	"
1030	48	72	41.0	8.8	335	1122	" , reversed after sampling
1035	48	72	41.0	8.8	335	1300	Plus
1100	48	72	41.0	8.8	335	1203	"
1130	49	72	41.0	8.8	335	1102	" , reversed after sampling
1135	49	73	41.0	8.8	335	1357	Minus
1200	49	74	42.0	8.8	335	1260	"
1230	49	72	41.0	8.8	335	1104	" , reversed after sampling
1235	49	72	41.0	8.7	335	1260	Plus
1300	49	73	40.0	8.7	325	1250	"
1330	49	74	40.0	8.8	315	1180	" , reversed after sampling
1335	49	75	42.0	8.8	325	1434	Minus
1400	49	75	42.0	8.8	325	1280	"
1430	49	74	42.0	8.8	325	1166	" , reversed after sampling
1435	49	74	41.0	8.8	325	1385	Plus
1500	49	74	41.0	8.8	325	1271	"
1530	49	74	41.0	8.8	325	1180	" , reversed after sampling
1535	49	76	43.0	8.8	325	1420	Minus
1600	49	75	42.0	8.8	315	2191	"
avg 48.6			avg 72.8	avg 8.76			

Note: Feed: Sea water alkalinity 94.5 ppm, pH 7.7, chlorides 14,200 ppm (as Cl).

Feed Rate: Rotameter reading 450 ml/min.

Polarity: Reversed hourly.

next reversal. The slight trend upward in concentration is explained by the fact that the operating day cited was at a time when the rotameter was fouled and needed cleaning. At the standard setting of 450 ml/min the actual flow rate was steadily decreasing. This decrease in flow rate did not affect the absolute output of the cell in grams per hour, but increased the concentration of the effluent. This fouling of the rotameter occurred in spite of the fact that the influent had been settled and was perfectly clear. The tube became brown in appearance and, as stated previously, gave decreasing flow rates for a given setting. This is shown as follows:

Fouling of Rotameter  
(Feedwater 48 F)

<u>Days of Operation</u>	<u>Rotameter Reading</u> <u>(ml/min)</u>	<u>Actual Measured Flow</u> <u>(ml/min)</u>
0	450	465
8	450	335

The rotameter was readily cleaned, however, either by passing through some diluted acid or by disassembling and cleaning with a test tube brush.

Throughout the entire 706 hours of operation the plastic case and other parts held up well. There was no evidence of deterioration or sea water attack. The electrodes themselves, however, showed definite signs of wear. Smooth at the start, they became rough and soft and the space gap separating them increased from 0.11 to 0.34 inch. The electrode erosion was caused in part by current reversal. It was noted that every time the current was reversed a quantity of graphite was discharged in the effluent. It was found that the carbon electrodes required replacement after about 700 hours of operation. A summary of the changes in characteristics of the Clorocel is shown in Table XXIII.

b. Clorocel Steriliser. The Clorocel Steriliser, the complete Paterson commercial unit loaned by the Infilco Company, was received from Camp LeJeune, North Carolina, after various laboratory and field tests had been conducted by the U. S. Navy. The unit was received in good condition. However, the plastic cases housing the ammeter and voltmeter were cracked and chipped and the rotameter tube was cracked. These items were repaired easily at Fort Story and caused no further trouble. The steriliser was operated continuously with sea water for 199 hours (24-hour days) being interrupted only by one 2-day week-end shutdown. The polarity was reversed every hour on the hour and samples of effluent were collected 1/2 hour after reversal during the day shift. The samples were analyzed for available chlorine and the results were averaged to obtain

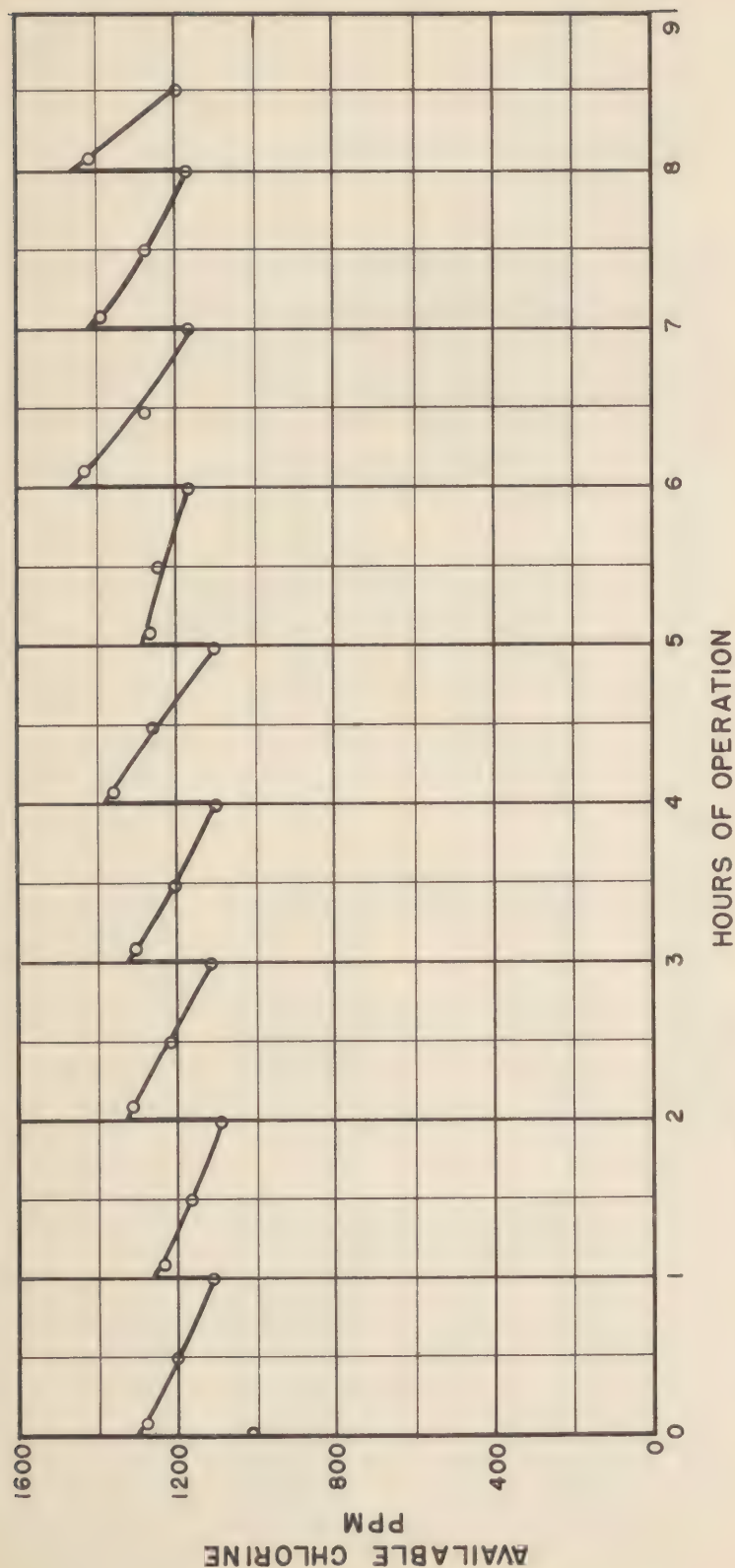


Fig. 21. Typical day's operation of Chlorocel during continuous run. Feed: Sea water, alkalinity 94.5 ppm, pH 7.7, chlorides 14,200 ppm (as Cl). Feed Rate: Rotameter reading 450 ml/min. Influent Temperature: 48.6 F (avg). Current: 41.0 amperes (avg). Voltage: 8.76 volts (avg). Polarity: Reversed hourly.



Table XXIII. Changes in Characteristics  
of the Clorocel through Long Operation

Accumulated Operating Days at Time of Sampling (days)	Sea Water Feed Alkalinity (ppm)	pH	Chlorides (as Cl) (ppm)	Feed Rate Rotameter Reading (ml/min)	Actual Feed Rate (ml/min)	Influent Temperature (F)	Effluent Temperature (F)	Current (amp)	Voltage (v)	Power (kw)	Available Chlorine (ppm)*	Available Chlorine (gm/hr)	Available Chlorine to 40 Amperes (gm/hr)	Gap between Electrodes (in.)
0	0	-	-	-	-	-	-	-	-	-	-	-	-	0.11
2	17	98.0	7.6	14,300	450	460	52.3	71.0	44.9	8.48	0.381	963	26.6	23.7
19	21	96.0	8.6	14,580	450	413	35.3	57.3	37.0	10.50	0.389	907	22.4	24.3
29	16	98.0	7.6	15,000	450	465	54.0	71.0	32.0	10.90	0.349	798	22.3	27.8
														0.34

\* Samples for available chlorine taken 1/2 hour after polarity reversal during periods when the polarity was being reversed hourly.

Table XXIV. Continuous Run of the Clorocel Steriliser

Operating Time (days)(hr)	Influent Temperature (F)	Effluent Temperature (F)	Actual Measured		Available Chlorine		Cell Economy (gm available Chlorine per kw/hr)
			Current (amp)	Voltage (v)	Feed Rate (ml/min)	Available Chlorine (ppm)*	
0	33.5	47.8	21.6	6.4	430	498	92.8
1	34.8	49.5	26.6	6.4	430	553	83.9
2	32.0	43.5	19.6	6.3	428	414	86.0
3	31.5	45.0	22.9	6.5	425	445	76.3
4	33.0	46.0	20.5	6.5	425	453	86.7
5	34.0	45.5	22.5	6.4	425	422	74.8
6	36.0	46.0	21.5	6.5	438	457	86.0
7	34.3	44.0	19.1	6.4	436	412	88.2
8	35.3	45.3	20.8	6.4	435	424	83.0
	avg 33.8		21.7	6.4			

\* During the day shift, samples were taken for available chlorine analysis 1/2 hour after polarity reversal. The sample values were averaged each day and adjusted to the 8-day average amperage of 21.7 for comparative purposes.

Note: Feed: Sea water, avg analysis, alkalinity 93.5 ppm, pH 8.1, chlorides 14,200 ppm (as Cl).  
 Feed Rate: Rotameter reading 450 ml/min.  
 Rectifier setting: Maximum, No. 6 position.  
 Operation: 24-hr/day.  
 Polarity: Reversed hourly.

the daily output figure. Measurements were also made of the influent temperature, the effluent temperature, the amperage, the voltage, and the flow rate. The results are shown in Table XXIV. It is seen that, with slight fluctuations, the output of the unit, in grams of available chlorine per hour, remained constant. There was no evidence of electrode fouling, a condition which would show up by a steadily decreasing output. The cell economy also remained essentially constant, indicating but slight erosion of the electrodes. Several times during the run the cell became clogged (probably with  $Mg(OH)_2$ ) and the desired flow rate could not be maintained with the existing head. Rather than disassemble the cell and clean it manually, a diluted acid solution was run through for 2 minutes. The acid dissolved the offending material and the cell again functioned normally.

16. Operation of the Clorocel with Current Furnished by Dodge Weapons Carrier. In view of the satisfactory operation of the Clorocel on previous tests, consideration was given to possible field applications. Common salt and a source of direct current are the only two items required for field operation. For large installations where a-c is available, only the rectifier which is normally part of the unit is required. For mobile units such as portable water purification and sea water distillation equipment, the engines being used to operate pumps and compressors can simultaneously drive small d-c generators. The British Army unit is designed in this manner.

An automobile generator has the voltage and capacity suited to the operation of a single Clorocel. The only available equipment at Fort Story that could provide a simulated field source of current was a 3/4-ton Dodge weapons carrier, which was believed to be suitable for the operation. It was intended to be used for field radio work and was equipped with a 12-volt, 55-ampere generator and a 6-cell, 12-volt battery. In addition, it had an extra large fan and radiator and was designed to operate at a standstill. For the recycling test, the Clorocel was mounted on the truck, using an assembly identical to the layout used in the previous test of continuous recycling of sodium chloride brine. The electrical layout is shown in Fig. 22, and photographs of the Clorocel assembly are shown in Fig. 23.

The following operational techniques were used: A salt solution was made up and poured into the feed funnel. The Stewart-Warner recirculating pump was turned on and the feed rate through the rotameter was adjusted to 450 ml/min: the engine was then started and the hand throttle was pulled out until the dashboard ammeter read + 55 amperes. The unit was then in operation. The raw salt solution flowed from the feed funnel through the rotameter into the Clorocel from which the effluent passed through a separator



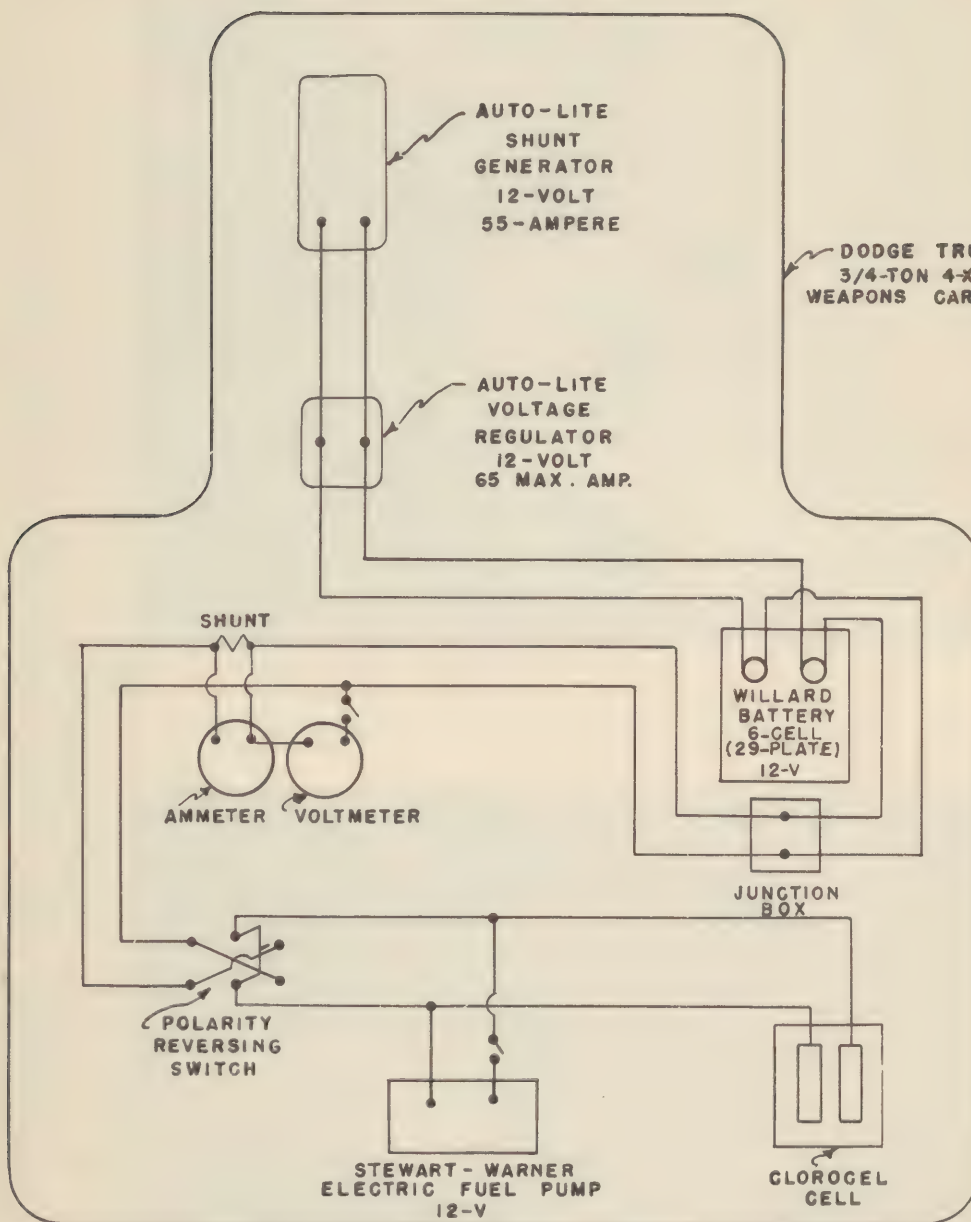
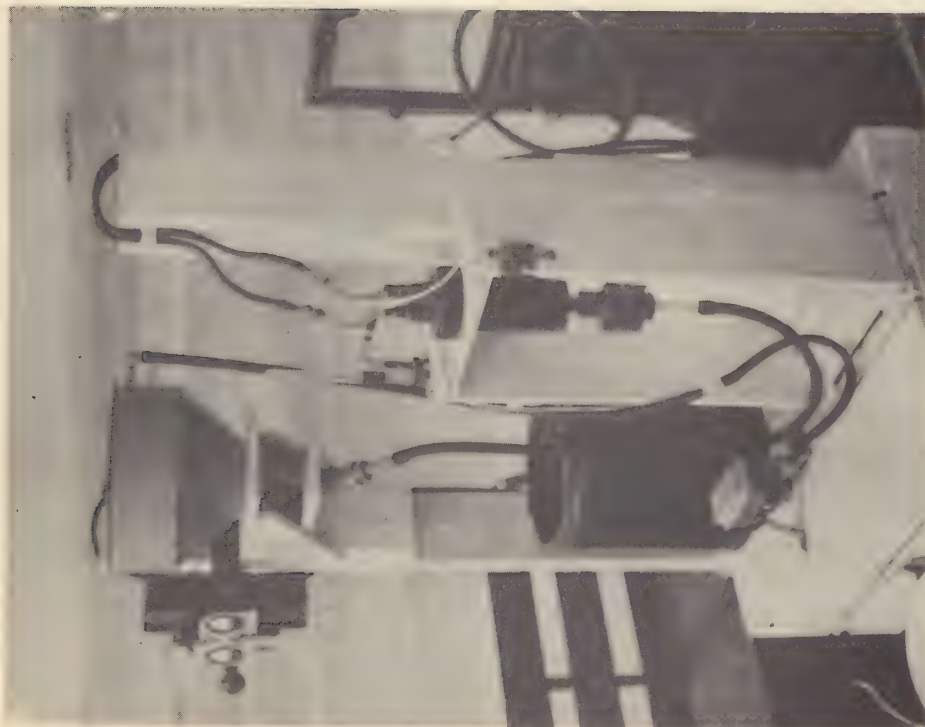


Fig. 22. Electrical diagram of the Sodium Hypochlorite Field Unit, Fort Story, Virginia.



190-3-10

Fig. 23. Clorocel unit. Current source, Dodge weapons carrier. Left: Closeup of Clorocel assembly; Right: Clorocel mounted on weapons carrier.



190-3-8

Table XXV. Field Test of the Clorocel Operated from  
3/4-ton Dodge Weapons Carrier with Continuous  
Recirculation of 2.44 Percent NaCl Solution

Time of Operation (hr) (min)	Dash Board Readings			Temperature in Feed		Current (amp)	Voltage (v)	Available Chlorine (ppm)
	Oil Pressure (lb/sq in.)	Ammeter	Engine Water Temperature (F)	Funnel (F)				
0 0	47	+55	158	65	55.0	10.0	0	
0 15	38	+55	160	78	52.0	9.5	-	
0 30	37	+55	160	89	55.0	9.4	2310	
0 45	37	+55	160	99	55.0	9.4	-	
1 1	36	+55	160	107	55.0	9.3	4120	
1 15	37	+55	160	114	58.0	9.4	-	
1 30	37	+55	160	120	56.0	9.3	5460	
1 45	38	+55	160	124	55.0	9.4	-	
2 2	38	+55	160	126	56.0	9.3	6360	
2 15	38	+55	160	129	56.0	9.3	-	
2 30	40	+55	160	129	55.0	9.4	6710	
2 45	40	+55	160	129	55.0	9.4	-	
3 3	40	+55	160	129	55.0	9.3	6640	
3 15	40	+55	160	129	55.0	10.0	-	
3 30	40	+55	160	128	53.0	9.5	6220	
3 45	40	+55	160	129	53.0	9.5	-	
4 1	41	+55	160	130	53.0	9.5	5850	

Note: Feed: At start, 8 liters tap water, 200 grams common table salt (solution recirculated).  
Feed Rate: Rotameter reading 450 ml/min.  
Polarity: Reversed hourly.  
Ambient Temperature: 70 F.



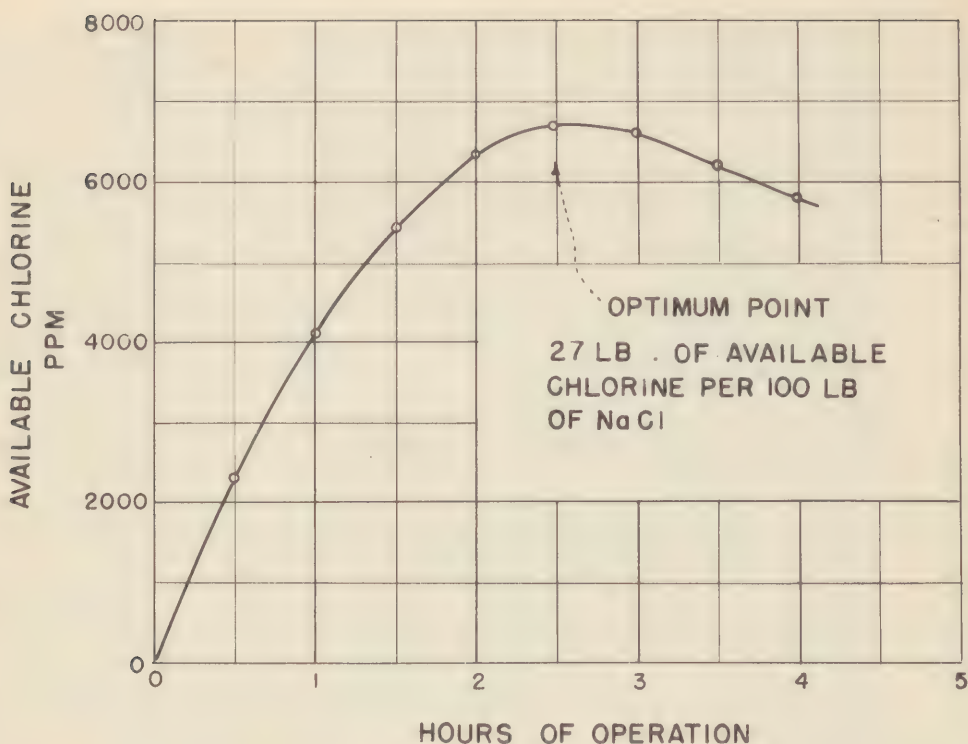


Fig. 24. Available chlorine vs hours of operation. Field test of Clorocel. Operated from 3/4-ton Dodge weapons carriers. Continuous recirculation of 2.44 percent NaCl solution. Feed: At start, 8 liters tap water, 200 grams common table salt (solution recirculated). Feed Rate: Rotameter reading 450 ml/min. Temperature of Recirculating Feed: 115 F (avg). Current: 54.8 amperes (avg). Voltage: 9.5 volts (avg). Polarity: Reversed hourly.

where the hydrogen was vented. (Although a cooling coil immersed in a water bath was provided as the next stage in the flow cycle, its use was omitted in the actual test.) Finally, the effluent passed into a 12-volt electrically driven fuel pump and was pumped back into the feed funnel, thus maintaining continuous recirculation. The polarity was reversed every hour.

The results of a trial run, made with a 2.44 percent NaCl solution circulated continuously for 4 hours are shown in Table XXV. Periodic readings were made for the oil pressure, the engine water temperature, the feed funnel temperature, the amperage, the voltage, and the available chlorine concentration. The generator did not overheat and the operating characteristics of the truck, such as oil pressure and engine water temperature, remained at satisfactory levels. The available chlorine concentration rose to a maximum of 6710 ppm in  $2\frac{1}{2}$  hours (Fig. 24), giving a

yield of 27 pounds of available chlorine per 100 pounds of NaCl. Since there were 8 liters in the system, this amounted to 1.135 pounds of available chlorine per 24 hours, if operated batchwise on a  $2\frac{1}{2}$ -hour cycle. At a dosage of 2 ppm, 1.135 pounds of available chlorine will disinfect 68,000 gallons of water. Based on a 24-hour day this is approximately 3000 gallons per hour and corresponds to the rated output of the Army standard 50-gpm diatomite purification unit.

### III. DISCUSSION

17. Comparison with Other Chlorine Solutions. Table XXVI gives the chlorine concentration of various chlorinating solutions.

Table XXVI. Comparison of the Concentration of the Clorocel Product with Other Chlorinating Solutions

Solution	Active Ingred- ient	Available Chlorine %	Remarks
Army drinking water	Cl	0.00004	Chlorinated to 0.4 ppm.
Clorocel effluent	NaOCl	0.089	Single pass of sea water through Clorocel at 450 ml/min.
Chlorine water	Cl, HOCl	0.4	Water saturated with chlorine gas.
Carrel-Dakin	NaOCl	0.43-0.48	Irrigant for wounds.
Zonite	NaOCl	0.9	Common personal disinfectant.
Clorocel product by recirculation	NaOCl	1.6	20 passes of 5% NaCl solution through Clorocel.
Javelle water	KOCl	2.5	Common household bleach.
Labarraque	NaOCl	3.5-5.8	Disinfectant.
Clorox	NaOCl	5.0	Common household bleach.
Commercial concentrate	NaOCl	15.0-16.0	Commercial product.
Liquid chlorine	Cl	100.0	Pure chlorine.

18. Summary of Test Results. Test results are summarized as follows:

a. In order to maintain the available chlorine output at a high level, the polarity must be reversed every hour when sea water is used. Sodium chloride solutions of concentration equivalent to sea water behave in a similar manner. The available chlorine concentration drops appreciably as a function of time at a given polarity and reversal is necessary in order to bring the concentration back to a high value. More frequent polarity reversals would give even higher outputs but would result in excessive electrode wear. A single test made with a 10 percent NaCl brine showed little drop in available chlorine concentration at a given polarity as compared with more diluted salt brines.

b. Wide ranges of acidity and alkalinity have only a negligible effect on the available chlorine output of the cell.

c. Wide ranges of temperature have only a negligible effect on the available chlorine output of the cell.

d. Dissolved iron has only a negligible effect on the available chlorine output of the cell.

e. The effluent is rather unstable and should be used soon after preparation lest it lose its strength.

f. The average operating characteristics of a new Clorocel on sea water are as follows:

Output (gm/hr available chlorine)	24
Concentration of effluent (ppm available chlorine)	890
Amperage	40
Voltage	8.9
Feed Rate (ml/min)	450
Polarity	reversed every hour

This hourly output will provide a dose of 2 ppm chloride for 3000 gallons of water. This volume of water corresponds by coincidence with the rated hourly output of the 50-gpm standard diatomite water purification unit.



g. The production rate of the Clorocel with sea water is somewhat less but it corresponds for practical purposes to the output obtained with NaCl brines of the same chloride concentration.

h. The study of the maximum yield obtainable by repeated passes showed that the optimum sodium chloride concentration of the feed is approximately  $2\frac{1}{2}$  percent. With a 2.44 percent solution of common salt in tap water, a yield of 38.6 pounds of available chlorine per 100 pounds of sodium chloride was obtained. This yield is comparable to bleaching powder (35 pounds of available chlorine per 100 pounds of material) but is appreciably lower than high test calcium hypochlorite (70 pounds of available chlorine per 100 pounds of material). During repeated passes the rate of chlorine production remains essentially constant for the first five passes. The total available chlorine rises up to the tenth pass but at a decreased rate. After the fifteenth pass the rate becomes negative, indicating that more hypochlorite is being decomposed than is being formed.

i. Continuous recirculation of a 2.44 percent NaCl brine, corresponding to sea water in strength, produced a solution containing a maximum of 6710 ppm available chlorine, or an equivalent available chlorine production of 27 pounds per 100 pounds of NaCl. During the first hour of continuous recycling the available chlorine concentration increases at a constant rate, indicating uniform electrical efficiency over this range. Total chlorine produced by recirculation rises to a maximum in 3 hours, after which further circulation results in no increase in chlorine production; actually, a slight loss in total available chlorine results after the maximum is reached. Approximately the same chlorine production is obtained by continuous recirculation as by repeated passes.

j. The durability studies of the Clorocel Steriliser and the Clorocel gave the following results:

- (1) The electrodes do not become fouled by sea water.
- (2) The carbon electrodes wear away and should be replaced every month if used continuously.
- (3) The plastic parts of the Clorocel Steriliser withstand normal operating wear satisfactorily.
- (4) The Clorocel Steriliser contains some comparatively fragile parts such as the rectifier, ammeter, and voltmeter, which will not withstand rough treatment.

19. Comparison of Electrolytic and Other Sources of Chlorine for Field Use. Selection of a preferred chlorinating agent or method of producing such agent in the field for military use requires consideration of such items as cost, weight, cubage, spare parts, simplicity of operation, auxiliary equipment, personnel training, critical materials, spoilage during storage, and expendable or returnable containers. Cost of field supplies cannot be ignored in the military picture, but must not be used as the sole criterion for choosing a product, as may be the case in commercial practice. To assist in the evaluation of various methods for providing chlorine in the field, cost, weight, and cubage data were compiled for each of the following five methods of supplying chlorine.

- a. High test calcium hypochlorite.
- b. Liquid chlorine.
- c. Bleaching powder.
- d. Sodium hypochlorite
- e. Electrolytic sodium hypochlorite.
  - (1) Using salt
  - (2) Using sea water

The data on the above-mentioned methods are presented in Tables XXVII, XXVIII, XXIX, and Fig. 25. The advantages and disadvantages of each chlorinating agent are discussed in the following subparagraphs:

a. High Test Calcium Hypochlorite. High test calcium hypochlorite (70 percent) which is at present the standard chlorinating agent for water treatment in the Corps of Engineers has the advantage of lower weight and lower cubage than any other chlorinating agent other than liquid chlorine. If desired, it can be added to the water supply without any special equipment as is done with the standard diatomite purification unit. In the present field water purification sets a small portion of the chemical is dissolved in the pretreatment tanks, hence making a hypochlorinator unnecessary.

The chief disadvantage of calcium hypochlorite is the corrosive action it has on metal containers. If the low moisture product (2 percent) is stored under ideal conditions in metal cans (terne plate) the containers will remain in satisfactory condition for a period of approximately 2 years. High moisture calcium hypochlorite (10 percent and above) even under ideal storage conditions

Table XXVII. Cost of Chlorine Carriers

Calcium Hypochlorite										Liquid Chlorine									
SOURCE: "List of Standardized Chemical Warfare Major Items," War Dept Supply Bulletin SB 3-22 (14 Feb 1945)										SOURCE: Corps of Engineers, Orange Book (15 Oct 1948)									
ONS Stock No.	Nomenclature	Unit of Measure	Spec	Price	Shipping Statistics					Stock No.	Nomenclature	Unit of Measure	Price	Weight (lb)	Cubage (ft)				
574104	Bleaching Material (Grade A)*	lb	O-B-441A	\$.22						51-3716-500-300	Chlorine, liquid, 16-lb cyl	ea	\$2.95	27	0.5				
574105	" " (Grade B)*	lb	O-B-441A	.06						51-3716-500-500	" " 20-"	"	3.12						
574106	" " (Grade C)*	lb	O-B-441A	.05						51-3716-500-700	" " 150-"	"	8.28	242	3.18				
SOURCE: Corps of Engineers, Orange Book (15 Oct 1948)										SOURCE: "Chemical Market Prices," Chemical and Engineering News (8 Nov 1948)									
Stock No.	Nomenclature	Grade	Unit of Measure	Spec	Price	Weight (lb)	Cubage (ft)	Chlorine, liq, cl, 41rd - 1b - \$0.094 " " tanks, wts, (freight allowed) 100 lb - \$2.40											
51-3436-600-300	Calcium Hypochlorite, Water Purification, 6-oz resealing can	AA*	can	O-B-441A	\$.29	.74	.02	Salt - Sodium Chloride											
51-3436-600-700	Calcium Hypochlorite, Purification, 5-lb can	AA*	lb	O-B-441A	.53	1.06	.03	SOURCE: Bureau of Federal Supply, Stock Catalog (July 1948)											
51-3436-600-700	Calcium Hypochlorite, 5-lb resealing can	A*	lb	O-B-441A	.10	1.30	-	Table salt; free running (evaporated) type B, iodized, Federal Spec No. SS-S-31											
*NOTE: Grade AA 70% available chlorine 2% moisture maximum Particle size: 8% through No. 14 sieve 90% retained on No. 100 sieve										56-S-2005 - 2-lb box 24 to case Case \$1.55 56-S-2010 - 10- " sack 6 to case " 1.20 56-S-2030 - 100- " " " " " 1.30									
Grade A 70% available chlorine No moisture or particle size requirement										SOURCE: "Chemical Market Prices," Chemical and Engineering News (8 Nov 1948)									
Grade B 35% available chlorine										Sodium chloride, bags, cl, - ton - \$18.60									
Grade C 30% available chlorine										Sodium Hypochlorite									
"Chemical Market Prices," Chemical and Engineering News (8 Nov 1948)										No quotations obtainable. Estimated price from \$.15 to \$.35 per gallon, 15% available chlorine by weight.									



Table XXVIII. Cost and Weight of Raw Material to Produce Available Chlorine by Repeated Passing of 2.44 Percent NaCl Solution through the Clorocel

Pass	Available Chlorine in Effluent (ppm)	Power (kw)	Power (cumulative avg) (kw)	Feed Rate (cumulative avg) (ml/min)	NaCl (per 100 lb of available chlorine)	Assuming Gasoline Consumption of 0.1 gal./kw-hr				Assuming Gasoline Consumption of 0.3 gal./kw-hr			
						Gas (per 100 lb of available chlorine)	Cost of Gas (\$ per 100 lb of available chlorine)	NaCl and Gas (per 100 lb of available chlorine)	Cost of Gas (\$ per 100 lb of available chlorine)	Lb of Gas (per 100 lb of available chlorine)	Cost of Gas (\$ per 100 lb of available chlorine)	Lb of NaCl and Gas (per 100 lb of available chlorine)	Cost of NaCl and Gas (\$ per 100 lb of available chlorine)
1	1820	0.554	0.554	505	1370	256	9.11	1626	36.51	768	27.33	2138	54.73
2	3360	0.588	0.571	505	745	286	10.20	1031	25.10	898	30.60	1603	45.50
3	4530	0.588	0.577	510	592	319	11.35	871	22.39	957	34.05	1509	45.09
4	5540	0.604	0.584	510	451	351	12.50	802	21.52	1053	37.50	1504	46.52
5	6310	0.614	0.590	512	356	388	13.80	784	21.72	1164	41.40	1560	49.32
6	7040	0.600	0.591	514	355	416	14.80	771	21.90	1248	44.40	1603	51.50
7	7600	0.594	0.592	514	329	451	16.10	780	22.68	1353	48.30	1682	54.88
8	8020	0.604	0.593	520	312	484	17.20	796	23.44	1452	51.60	1764	57.84
9	8480	0.600	0.594	519	295	516	18.40	811	24.30	1548	55.20	1843	61.10
10	8770	0.610	0.595	519	285	556	19.80	841	25.50	1668	59.40	1953	65.10
11	8920	0.590	0.595	519	280	601	21.40	881	27.00	1803	64.20	2083	69.80
12	9170	0.590	0.595	519	280	638	22.70	911	28.16	1914	68.10	2187	73.56
13	9380	0.590	0.594	520	273	672	23.90	939	29.24	2016	71.70	2283	77.04
14	9310	0.570	0.593	520	268	725	25.90	977	31.26	2187	77.70	2455	83.06
15	9460	0.570	0.591	520	264	766	28.70	1030	32.58	2298	81.90	2562	87.18
16	9590	0.570	0.593	520	262	807	30.94	1069	33.94	2421	86.10	2683	91.34
17	9600	0.560	0.588	520	260	850	30.30	1110	35.50	2550	90.90	2810	96.10
18	9600	0.550	0.588	521	260	1000	35.60	1260	40.80	3000	106.80	3260	112.00

Note: Feed: 1st pass, 8 liters tap water, 200 grams common table salt.

Gasoline: Assumed, sp grav 0.675, cost \$.20 per gallon.

NaCl: Cost \$.02 per pound.

Table XXIX. Cost, Weight, and Cubage of Chlorine Materials  
(All calculations based on 100 pounds of available chlorine)

Source of Chlorine	Cost	Weight (lb)		Cubage (cu ft)
		Material	Container	
<b>CALCIUM HYPOCHLORITE - 70% available chlorine</b>				
Grade AA - 2% moisture - 6-oz can	\$110.49	143	281	7.6
" " - 5-lb can	75.79	143	150	4.3
Grade A - 5-lb can	14.30	143	186	
<b>LIQUID CHLORINE - 16-lb cylinder</b>				
150-lb cylinder	19.66	100	73	3.3
	5.52	100	61	2.1
<b>BLEACHING POWDER - 35% available chlorine</b>				
Grade B - 5-lb can	17.16	286		
SODIUM HYPOCHLORITE - Solution 15% available chlorine	\$15 to \$30 (estimated)	666	640	40.0
Note: No bulk price quotation obtainable. Shipped in 5-gal carboys estimated at 40 lb empty and 2.5 cu ft. 16 carboys required.				
<b>ELECTROLYTIC CHLORINE -</b>				
<b>A. - 2.44% sodium chloride brine</b>				
NaCl - \$.02 per lb Gasoline - \$.20 per gal				
1. Gasoline calc at 0.1 gal per kw-hr				
Single Pass - (NaCl)	\$27.40			
	9.11			
Five Passes - (NaCl)	7.92			
	13.80			
2. Gasoline calc at 0.3 gal per kw-hr				
Single Pass - (NaCl)	27.40			
	27.33			
Five Passes - (NaCl)	7.92			
	41.40			
<b>B. - Sea water - Gasoline \$.20 per gal</b>				
1. Gasoline calc at 0.1 gal per kw-hr	13.80			
2. Gasoline calc at 0.3 gal per kw-hr	41.40			
Note: Weight and cubage based on materials only. Salt density estimated at 100 lb per cu ft, gas at 5.6 lb per gal.				

will show serious container corrosion in from twelve to fifteen months. Exposure to warm humid conditions hastens the rate of container corrosion.

The low weight, low cubage, and minimum operating technique required of field personnel, and the fact that no additional equipment is necessary to add the chemical to the water make high test calcium hypochlorite the preferred source of chlorine for the field water purification units.

b. Liquid Chlorine. Liquid chlorine was formerly used in the mobile water purification unit. This unit is no longer standard having been replaced by the 50-gpm diatomite unit which uses calcium hypochlorite in place of the liquid chlorine. Liquid chlorine has the disadvantage that a special, rather complicated piece of apparatus is required for adding the chlorine to the water being treated. This results in extra equipment at each water point with the additional problems of maintenance and spare parts. The cost, weight, and cubage of liquid chlorine are affected considerably by the size of the cylinder used. The 150-pound container requires much less weight and cubage, and it costs less per pound of available chlorine than the 16-pound container. However, for ease of handling, the small cylinder was issued to all mobile field water purification units. The liquid chlorine cylinders are returnable for refill, and this presents a considerable shipping problem in the overseas theaters. Such cylinders cannot be treated as expendable in view of their initial cost and the critical material contained in them. The 150-pound cylinder is valued at \$19.72 and the 16-pound cylinder at \$9.57.

Liquid chlorine is a toxic agent and some dangers are involved in handling the chemical.

c. Bleaching Powder. Bleaching powder is comparable to high test calcium hypochlorite in general properties but because of its low available chlorine (30 to 35 percent) requires at least twice as great a weight of material to provide the same amount of available chlorine as the high test (70 percent) calcium hypochlorite.

d. Sodium Hypochlorite. Sodium hypochlorite cannot be shipped as a dry chemical but must be prepared in water solution. The usual commercial strength is a 16 percent solution; hence, a large quantity of water would have to be transported to the field to obtain a given amount of sodium hypochlorite.

In addition, glass carboys, or bottles are required for storing the solution -- a definite disadvantage in shipping the chemical to the field.



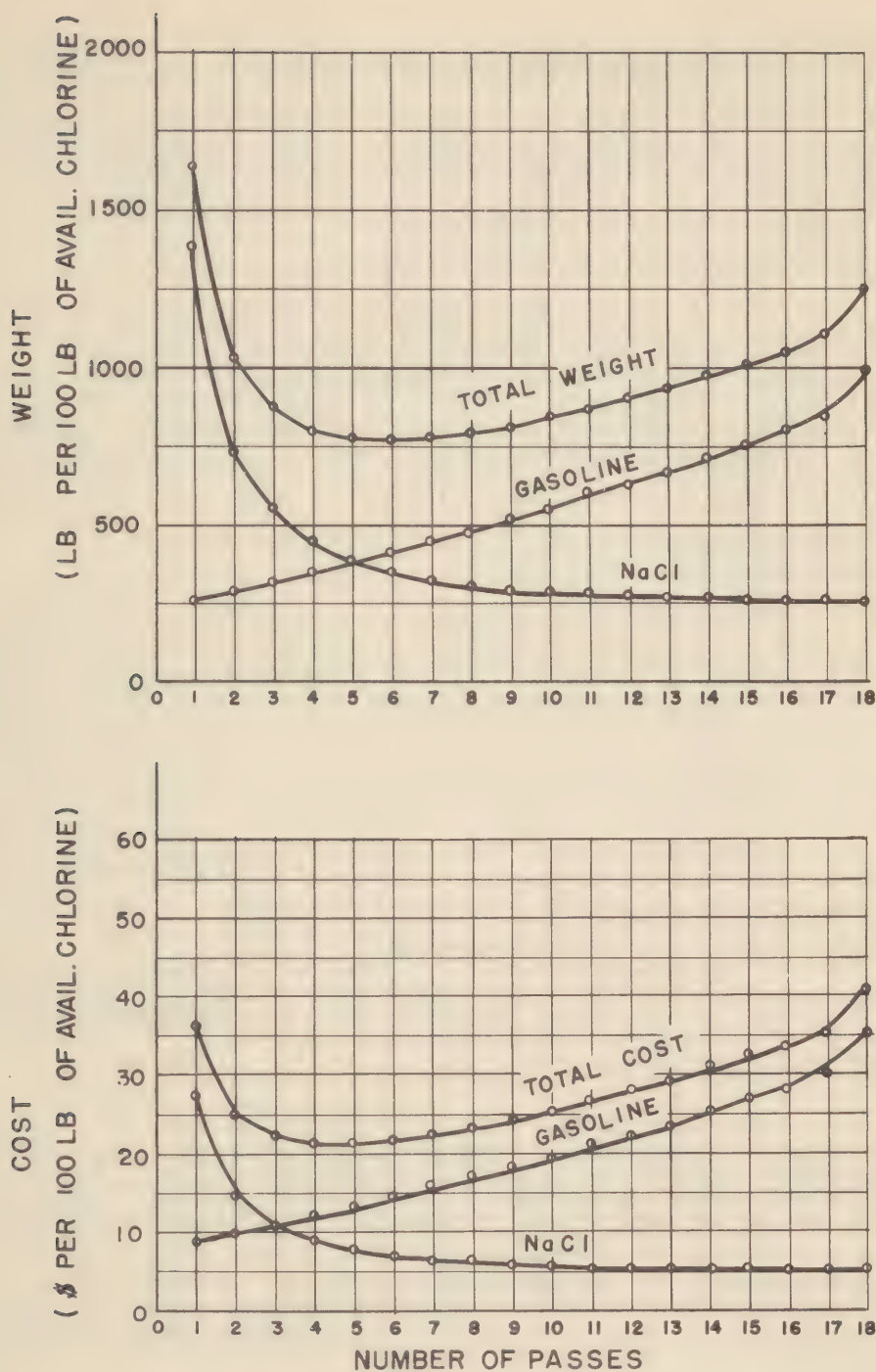


Fig. 25. Cost and weight of raw material to produce available chlorine by repeated passing of 2.44 percent NaCl solution through Clorocel. Cost of NaCl, \$0.2 per pound. Cost of gasoline, \$.20 per gallon. Gasoline consumption, 0.1 gallon per kw-hr.

e. Electrolytic Sodium Hypochlorite. In evaluating the weight of materials and cost of supplies that must be shipped to the field to produce sodium hypochlorite electrolytically, it is necessary to consider both the sodium chloride needed for the salt brine and the gasoline required to produce the direct current for operation of the cell. For this reason, the salt and gasoline have been itemized separately in Table XXIX.

If an electrolytic hypochlorite cell were to replace the calcium hypochlorite in the portable diatomite purification sets, it would be necessary to issue salt (sodium chloride) in place of calcium hypochlorite. It could not be assumed that salt could be obtained locally wherever the Army units might operate. It is obvious from Table XXIX that from the standpoint of weight of expendable materials shipped to the field calcium hypochlorite is the much preferred source of chlorine for the present standard portable water purification equipment.

If the Clorocel were substituted for calcium hypochlorite in the portable water purification sets, a d-c generator and an electrolytic cell would be required as additional equipment. Calcium hypochlorite, on the other hand, can be added to the water in the pretreatment tanks without any additional equipment as is now done with the standard 15-gpm and 50-gpm diatomite units.

The Clorocel is easy to operate and gives dependable performance. The cell is simple in construction and is built of inexpensive materials, namely, ebonite and carbon. It uses the chemical raw material, common salt, which is found the world over and requires no complex manufacturing process to prepare. Salt is easily packaged and can be stored indefinitely. In emergencies, it can be obtained from local supplies but this is seldom possible with regard to calcium hypochlorite.

The electrolytic chlorine cell can best be considered for special applications. Under emergency conditions, where the supply of calcium hypochlorite or bleaching solutions such as Clorox are exhausted and ordinary salt can be procured without difficulty, the electrolytic cell provides an excellent source of emergency chlorine. In overseas base camps or occupied areas where both electric power and salt are provided locally the hypochlorite cell could reduce the quantities of calcium hypochlorite to be shipped overseas.

It is standard practice to chlorinate the distillate from the Army's sea water distillation units. These units have sea water brine available at all times. An electrolytic chlorine cell appears to be adaptable to these units. However, the size of the field unit affects the advantage of the electrolytic unit over the



high test calcium hypochlorite. For example, the 60-gph thermocompression unit has a maximum yearly production of approximately 400,000 gallons of distillate per year. To chlorinate this quantity of distillate to 2 ppm requires approximately 10 pounds of 70 percent calcium hypochlorite. Assuming excessive waste of the chemical the quantity of high test calcium hypochlorite needed per year for the above-described unit should not exceed 50 pounds. It would not be advantageous to substitute an electrolytic cell, d-c generator, and power to drive the generator, in place of the above-stated yearly requirement of calcium hypochlorite. However, when the size of distillation units reaches 1200 gph (these are now under development), and under conditions where an electric current supply will probably be an integral part of the unit, an electrolytic cell such as the Clorocel may prove to be an advantage over calcium hypochlorite.

On shipboard, where sea water is available at all times to furnish the salt brine, the electrolytic hypochlorite may be preferable to calcium hypochlorite or sodium hypochlorite solution. Selection of the source of chlorine aboard ship would depend on a number of considerations such as total quantity of chlorine required, difficulty experienced in storage and supply of calcium hypochlorite or sodium hypochlorite solution at base ports, convenience of operation, and importance of weight, space, and electric power. The generation of hydrogen together with the sodium hypochlorite makes adequate ventilation necessary when such units are installed aboard ship.

#### IV. CONCLUSIONS

20. Conclusions. It is concluded that:

a. The Clorocel can be operated satisfactorily with sea water.

b. The Clorocel is sufficiently simple in operation so that military personnel in the field can operate it with a minimum amount of training.

c. The Clorocel can be operated satisfactorily with an automobile type d-c generator.

d. High test calcium hypochlorite is superior to electrolytic sodium hypochlorite for military field use for the following reasons:

(1) It requires a lesser weight and volume of raw materials to produce a given amount of available chlorine than does the electrolytic method.



(2) Special equipment such as an electrolytic cell, a generator, or other source of power is not needed.

e. Under conditions where the normal supply of calcium hypochlorite is exhausted and a ready supply of common salt or sea water is available, the Clorocel is considered a satisfactory emergency source of hypochlorite.

#### V. RECOMMENDATIONS

21. Recommendations. It is recommended that:

a. Current investigation of electrolytic sodium hypochlorite equipment be terminated.

b. The unit be standardized if a future requirement for special military situations exists.

Submitted by:

Don C. Lindsten *erk*  
DON C. LINDSTEN  
Water Supply Branch

Ernest H. Sieveka *erk*  
ERNEST H. SIEVEKA  
Water Supply Branch

Forwarded by:

Chas R Keatley  
CHARLES R. KEATLEY  
Chief, Water Supply Branch

Approved 1 April 1949 by:

Steven Malevich  
STEVEN MALEVICH, Lt Col, CE  
Chief, Technical Department IV





APPENDIX A

## AUTHORITY

Letter from the Office of the Chief of Transportation to the Chief of Engineers, Dated 20 August 1947, File TCRAE-M 414/400.112, Subject: Test of Chlor-O-Cel Unit, with 1 Indorsement and 1 Inclosure



WAR DEPARTMENT  
Office of the Chief of Transportation  
Washington 25, D.C.

TCRAE-M 414/400.112

20 August 1947

SUBJECT: Test of Chlor-O-Cel Unit

TO: Office, Chief of Engineers, Washington 25, D. C.

Reference:

a. T. C. letter, subject: Test of Chlor-O-Cel Unit, File TCRAE-M 414/400.112 dated 28 May 1947 w/1st ind. Office, Chief of Engineers, dated 10 June 1947.

1. Appreciation is expressed to your office for the courtesy and cooperation extended to representatives of the Transportation Corps who attended subject tests on 17 July 1947 at the Engineer Research and Development Laboratories, Fort Belvoir, Va.

2. Pursuant to discussions held between representatives of the Transportation Corps and your office during subject tests, the following desired requirements for subsequent tests are submitted as being of interest to the Transportation Corps.

a. That a durability test be made to determine the values of the Chlor-O-Cel Unit in continuous operation.

b. That a cost analysis be made of the operation of the Chlor-O-Cel Unit for comparison with the present method of providing bulk sodium hypochlorite for use in potable water.

3. The latter method of supplying chlorine to Transportation Corps vessels is currently used and a cost estimate of this method is being prepared by this office and will be forwarded for your consideration when available.

FOR THE CHIEF OF TRANSPORTATION:

WATER H. KENNETT  
Lt. Colonel, T.C.,  
Assistant  
(/s/ John W. Koletty)  
( Lt.Colonel, TC )



SUBJECT: Test of Chlor-O-Cel Unit (Work Order No. DWS 3194)

ENGNC 920 Aug 47)

1st Ind

Office, Chief of Engineers, Washington 25, D. C. 10 September 1947

TO: The Commanding Officer, Engineer Research & Development  
Laboratories, Fort Belvoir, Virginia

1. It is requested that the additional tests as outlined in paragraph 2 of the basic letter be incorporated in the investigation of the Chlor-O-Cel Unit now under way at the Engineer Research and Development Laboratories, which is being carried out under development project WS 768 entitled, Water Disinfection Methods. Further, it is requested that a separate project report be submitted covering the investigation of the Chlor-O-Cel unit upon completion of the testing program.

2. Copies of correspondence received from the Transportation Corps relative to Vessel Sanitation are inclosed as a matter of information. The cost estimate referred to in paragraph 3 of the basic letter will be forwarded when received from the Transportation Corps.

BY ORDER OF THE CHIEF OF ENGINEERS:

G. E. LINKSWILER  
Colonel, Corps of Engineers  
Assistant, Engr Research & Dev Div  
Military Operations

1 Incl

Cy ltr to Mr.  
Yarger, 22 Jul 47  
w/2 Incls thereon

TCWTS-MR

Vessel Sanitation

Mr. Yarger  
Office Chief of Engineers  
Rm. 2021, Bldg. T-7  
Gravelly Point, Va

Mr. C. E. Hoch  
M & R Branch

22 July 47

1. Herewith, as I promised, is excerpt from Joseph Demody's report stating objections to use of calcium hypochlorite on board U. S. Army transports. In addition, I am sending you a pertinent extract from the U. S. Public Health Service's Administrative Guide for Plan Approval, Inspection and Certification of Vessel Sanitation.

2. I appreciated the opportunity of visiting with you the other day and seeing the final work that your people are doing down at the laboratory. I have not as yet obtained the cost of the requirements for the vessel but expect to have the information in the near future when I will again contact you.

C. E. HOCH

2 Incls

1. Excerpt from Joseph Dermody's report
2. Extract fm U. S. Public Health  
Service's Adm Guide

Excerpt from Report of Survey of Environmental Sanitation  
Aboard USAT ZEBULON B. VANCE by Joseph L. Dermody, S. A.  
Engineer (R) U. S. Public Health Service, April 30, 1947,  
at N. Y.

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"The mechanical operation of the units is not entirely satisfactory due to the use of the calcium salt in the stock solution rather than the more soluble sodium salt. The chief difficulty encountered is the clogging of the feed lines. This condition occurs despite precautions taken to assure the removal of particles of solid material."

EXTRACT FROM U. S. PUBLIC HEALTH SERVICE'S ADMINISTRATIVE  
GUIDE FOR PLAN APPROVAL, INSPECTION AND CERTIFICATION OF  
VESSEL SANITATION

---

1.72 Chlorination.- When water is to be regularly disinfected by chlorination, the chlorine should be applied in the form of a hypochlorite solution by means of an approved commercial hypochlorinator. The hypochlorinator should be constructed or equipped so that the flow of the hypochlorite solution may be observed. Its capacity should be determined on the basis of the maximum rate of flow of water and the treatment required to produce a satisfactory chlorine residual (not less than 0.2 ppm). A sampling cock should be provided at an appropriate place in the system for taking samples for checking the chlorine dosage and operating efficiency of the feeder. A commercial testing kit for determining the chlorine residual should be furnished with the hypochlorinator.

When water is treated regularly by chlorination, provision should be made for a baffled holding tank of sufficient capacity to provide a suitable contact period for the chlorine and the water. This period of contact should be provided before any water is delivered to the distribution system and should be figured on the basis of maximum rate of flow through the contact tank. When a normal dosage of chlorine is applied, the contact period should be at least 20 minutes. When super-chlorination is practiced, a lesser period of contact may be satisfactory.

When the water is treated regularly by superchlorination and dechlorination with sodium thiosulfate, a mechanical means should be provided for injecting the sodium thiosulfate. Granular activated carbon for dechlorination should not be used unless the plans covering its use are approved in each case.



APPENDIX BSUMMARY OF LITERATURE ON  
ELECTROLYTIC HYPOCHLORITE CELLS



## SUMMARY OF LITERATURE ON ELECTROLYTIC HYPOCHLORITE CELLS

1. American Commercial Cells. The common method of preparing sodium hypochlorite in the United States is by the interaction of sodium hydroxide and gaseous chlorine, as follows:



The electrolytic method has not been used commercially on a large scale.

Thompson<sup>1</sup> referred to hypochlorite cells produced by the Electro Chemical Company, Dayton, Ohio. Each cell consists of a series of vertical carbon electrodes in a horizontal trough. The carbon electrodes, which serve as vertical baffles, are located well below the surface of the brine to reduce the escape of chlorine. Glass plates support the electrodes and assure that the brine travels through the cell, over and under the baffles in a continuous path without short circuiting. The solution enters one end and leaves the other, thus making only one pass. Performance characteristics are as follows:

Current	- 70 amperes at 110 volts
Brine	- 60 grams NaCl per liter
Rate	- 3 liters per minute
Active chlorine	- 6 to 7 grams per liter
Energy efficiency	- 0.16 kg per kw-hr

A hypochlorite cell designed by the Valhalla Company, Chicago, Illinois, was reported by the editors of a British chemical journal<sup>2</sup> because of the interest in hypochlorite during the war. In this cell, 6 percent brine made up with commercial salt flowed by gravity through troughs containing electrodes carrying 18 to 20 amperes at 110 volts d-c. The unit produced 15 gph of 0.55 percent NaOCl, equivalent to 283 grams, or 0.63 pound of chlorine per hour. This represents 5 grams of chlorine per liter. Rate of flow was automatically controlled by a flow control valve and orifice. Brine concentration and flow rate control the temperature.

2. German Commercial Cells. Foerster<sup>3</sup> provided an excellent basic reference in which the principles and applications of

1. Maurice de Kay Thompson, Theoretical and Applied Electrochemistry (3rd ed.; New York: The Macmillan Company, 1939), 289-297.
2. "A New Chlorinator," editorial in The Chemical Age, 48:129 (23 January 1943).
3. Fritz Foerster, Elektrochemie Wässriger Lösungen (Leipzig: Verlag Von Johann Ambrosius Barth, 1923), 669-708.



hypochlorite cells were discussed in detail. The following summary of characteristics of various German hypochlorite cells is abstracted from Allmand and Ellingham<sup>4</sup>:

The German cells generally were shallow vessels of concrete, metal, or wood construction, with graphite, metal, or platinum electrodes. Losses by side reactions were kept at a minimum by the use of various devices for controlling the circulation of the electrolyte. Such cells were capable of producing hypochlorite solutions containing up to 30 grams per liter of active chlorine, equivalent to 100 pounds of chlorine per 24 hours. The majority of the cells provided a means of recirculating the electrolyte to bring it up to the desired strength. Both the batch and the continuous processes were employed.

A summary of the operating characteristics of several of the better known German cells follows:

Type	Percent NaCl Used	Grams Active Chlorine per liter	Kwh per Kg of Act. Chlorine	Kg of Salt per Kg of Act. Chlorine	Chemical Added
Kellner (vertical)	15	12	6.5	12.5	K <sub>2</sub> CrO <sub>4</sub>
Haas-Oettel	17	12.3	6.4	14	-
Schuckert	15	20	6	7.5	Na resinate
Kellner (horizontal)	15	25	6.0 - 6.3	4 - 6	Organic Sulphur cpd

The operating temperatures ranged from 12 to 25 C.

3. Hypochlorite Cells for Water Treatment. A bulletin published by the Everson Manufacturing Corporation lists fifty or more swimming pool installations of the hypochlorite cell throughout the Midwest.<sup>5</sup> Direct current is obtained with a rectifier for these sterilizers. Special U-shaped carbon electrodes are mounted in a horizontal open tank. Flow is by gravity. Fifteen pounds of salt produce approximately 1 pound of available chlorine.

4. A. J. Allmand and H. J. T. Ellingham, The Principles of Applied Electrochemistry (2nd ed.; New York: Longmans, Green, and Company, 1924), 366-391.

5. "Everson Safety Electric Sterilizer," Bulletin No. 1000A (Chicago, Illinois: Everson Manufacturing Corporation, 1948).

Sanders<sup>6</sup> stated that several oil companies in the East Texas oil fields, as a matter of operating economy, replaced liquid chlorine with electrolytically produced hypochlorite as a method for chlorinating salt brines. A series of carbon electrodes were set up in troughs through which the salt brine flowed. The Sun Oil plant used a 5-hp, 3-phase, 440-volt a-c induction motor to drive a generator which put out 275 to 300 amperes at 7 volts to chlorinate 4000 to 5000 barrels of salt brine daily. Oxides of Mg and Ca built up on the cathode, necessitating reversal of electrodes at 24-hour intervals. Electrodes were spaced at  $3/4$  to 1 inch. Continued operation indicated that with current at  $1\frac{1}{2}$  cents per kwh this method was cheaper than buying liquid chlorine.

In a progress report of the Atlantic Coast Stations, Castell<sup>7</sup> stated that polluted sea water was filtered through sand and passed through a metal duct containing a carbon electrode in order to serve as a fish plant water supply. At 6 volts and 20 amperes an effluent of 8 to 10 gpm contained 7 to 10 ppm of active chlorine.

According to Biggs<sup>8</sup>, the Poplar municipal cell was installed by a health officer in an English city. The cell was patterned after the old Hermite cell and was used  $MgCl_2$  together with the NaCl to produce a more stable hypochlorite in accordance with the theory of the day. A small amount of sodium hydroxide was added to the product as a preservative. The product lost from 2 to 10 percent of its strength after standing for 6 weeks. Incrustations at the cathode were removed by periodic washing. A solution containing 5 percent sodium chloride and 1 percent magnesium chloride flowed by gravity through four troughs, each trough containing ten elements, consisting of a pair of zinc plates as cathodes and a platinum anode. The elements were connected in series on a 230-volt main line, each plate using 5.6 volts with a resultant current consumption of 16 amperes. Temperatures ranged from 30 to 35 C. For 1 kilogram of active chlorine, 7.2 kilowatt hours were required. For 1 kilogram of active chlorine, 13.5 kilograms of salt were necessary.

4. Other Military Hypochlorite Cells. In April 1943, the Wallace and Tiernan Company, Incorporated, presented to the ERDL a

6. T. P. Sanders, "Electrolytic Chlorinator Used on East Texas Disposal Projects," *The Oil and Gas Journal* 41:31-2 (23 July 1942).
7. C. H. Castell, "The Fish Plant Water Supply," *Progress Reports of the Atlantic Coast Stations* 36: 14-18 (December 1946).
8. Charles V. Biggs, "The Hermite Electrolytic Process at Poplar," *Transactions of the Faraday Society* 11:182-198 (February 1907).



letter report in response to a request for the design and testing of an electrolytic chlorine cell. The cell consisted of two square platinum electrodes, 2 inches on a side, mounted vertically 0.27 inch apart. The cell was pressure tight and inserted in the line between the hypochlorinator discharge and the normal point of application. Brine was pumped through the cell from the standard hypochlorite solution bag. Electrical energy was furnished by a standard automobile type generator belt driven from the engine. The electrical output of the generator was indicated by an ammeter and was controlled by a field rheostat. Tests were conducted with a salt brine which was 11 percent saturated (equivalent to sea water). Current efficiencies on this solution ranged from 80 to 90 percent. Results indicated that 18 to 20 pounds of sodium chloride produced 1 pound of chlorine. Current consumption was at the rate of 1 kilowatt hour per 0.333 pound of chlorine produced. The effect of various generator loadings of the gasoline engine on the pumping characteristics of the unit was studied. The experimental cell was made from Lucite, which is subject to distortion above 120 F.

The ERDL recommended that further investigation of equipment for electrolysis of brine or sea water as a source of chlorine be discontinued. The quantity of salt to be transported as compared with calcium hypochlorite and the lack of readily available local supplies of either salt or sea water were the primary reasons for the recommendation.

Water purification apparatus for treating water with electrolytic hypochlorite was patented in June 1944.<sup>10</sup> The object of this invention is to provide a self-contained unit suitable for treatment of water in connection with a water cart for a military unit in the field. The pump, filter, and electrolytic chlorine cell are fabricated together in one piece. The crank that drives the hand pump simultaneously drives a small generator similar to that used on motorcycles. The generator will deliver about 6 volts and 1 ampere, depending on the size of the cell. A container for salt brine is housed in the lower part of the unit and brine is drawn up through the cell by the pump suction. The rate of brine feed is regulated by a calibrated orifice. A diatomaceous or carbon type filter is suggested.

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9. Ltr Rpt, "Electrolytic Chlorine Generating Accessories for the Army Portable Water Purification Unit," from the Wallace and Tiernan Company, Inc., to the ERDL April 1943, 671 (WS 346 G).

10. David J. Evans, "Water Purification Apparatus," U. S. Patent No. 2,351,113 (13 June 1944).



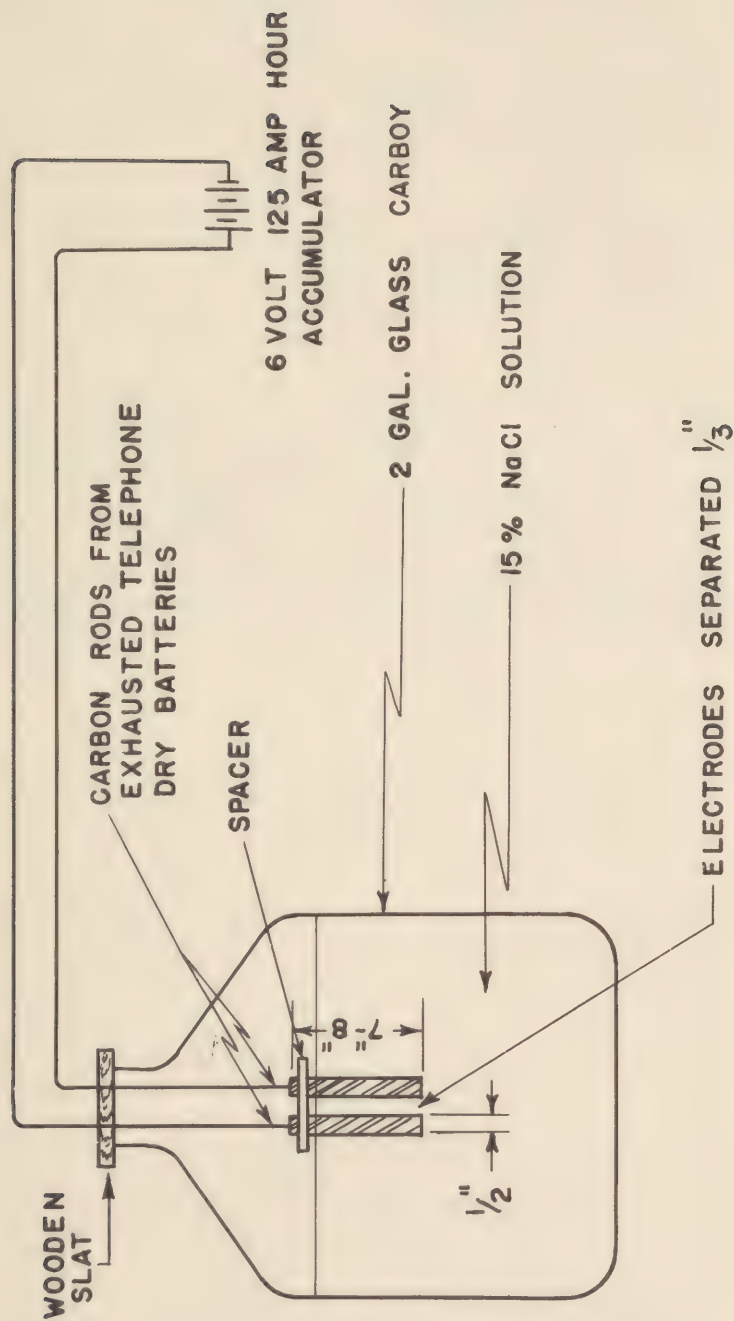


Fig. 26. Field Expedient Electrolytic Sodium Hypochlorite (Captain E. S. Anderson, Royal Army Medical Corps).

Captain Anderson<sup>11</sup> developed a method of preparing electrolytic sodium hypochlorite solutions in the field (Fig. 26). His apparatus consists of a 2-gallon glass carboy for holding the solution, two carbon rods from an exhausted telephone dry battery for electrolyzing the solution, a spacer for the rods, and a 6-volt, 125-ampere-hour accumulator. The hypochlorite is prepared batch-wise from common issue salt. Two gallons of 15 percent solution are made up and electrolyzed for 5 hours. A typical run is as follows:

Atmospheric temperature	75 to 90 F
Initial solution temperature	100 F
Final solution temperature	113 F
Amperage	9.4
Analysis of product	0.43% chlorine

The anode disintegrates and is reduced from its starting diameter of  $\frac{1}{2}$  inch to  $\frac{1}{4}$  inch after 20-gallon production (10 runs). The cathode does not disintegrate but becomes encrusted with a white coating. The coating is easily removed with sandpaper and, in any event, either electrode is easily replaced. No mention is made of the possibility of reversing the polarity to give the electrodes even wear. It is recommended that the 6-volt, 125-ampere-hour accumulator, issued to all units for radio work, be recharged after each run.

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11. E. S. Anderson, "The Electrical Preparation of Sodium Hypochlorite, a Simple Method of Preparing an Efficient General Antiseptic," *Journal of the Royal Army Medical Corps* 82:217-223 (May 1944).

APPENDIX C

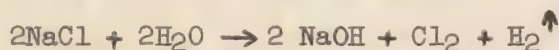
## THEORY OF ELECTROLYSIS OF SODIUM CHLORIDE





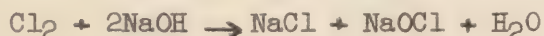
## THEORY OF ELECTROLYSIS OF SODIUM CHLORIDE

Sodium chloride is electrolyzed by passing direct current through the molten material or through an aqueous solution of the salt. The electrolysis of an aqueous solution is used widely in the chemical industry for the production of caustic soda, hydrogen, chlorine, and, to a lesser extent, sodium hypochlorite and sodium chlorate. The electrolysis proceeds according to Faraday's law which states that the quantity of chemical change produced, expressed in equivalents, when an electric current is passed through an electrolyte, is directly proportional to the quantity of electrical current passing. The law is independent of such factors as temperature, current density, and salt concentration. An aqueous solution of sodium chloride consists of the following ions:  $H^+$ ,  $OH^-$ ,  $Na^+$ , and  $Cl^-$ . When direct current is passed through the solution, the  $H^+$  ions gain electrons at the cathodes producing hydrogen gas. The  $Cl^-$  ions lose electrons at the anode producing chlorine gas. Left in solution are  $Na^+$  and  $OH^-$  or caustic soda. The reaction may be written according to the following equation:



The current efficiency for the above-mentioned reaction, based on Faraday's law, is calculated as the ratio of the chemical change produced to that which should theoretically be produced for the quantity of current flowing. The quantity of current required to produce one chemical equivalent (35.5 grams of chlorine) is 96,500 coulombs (ampere seconds). This quantity of current is known as the Faraday. The electrochemical equivalent is the quantity of chemical discharged by a given amount of current and may be expressed as mg/sec/amp or g/hr/amp. For chlorine this value is 1.3228 g/hr/amp.

Manufacturers of chlorine cells using specially designed units make great efforts to keep the three products  $H_2$ ,  $Cl_2$ , and  $NaOH$  separate. In the sodium hypochlorite cells such as the Clorocel, the products are readily intermingled and sodium hypochlorite is formed according to the following equation:



Examination of the preceding equation might suggest that half the chlorine is lost by this reaction since  $NaCl$  is reformed. This is true in a sense, but the important consideration is that the oxidizing power has remained unchanged; that is, one molecule  $NaOCl$  is equivalent to two atoms of "free" chlorine ( $Cl_2$ ) in oxidizing power.

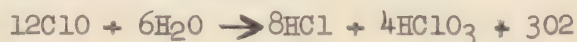
Chemical decomposition of sodium hypochlorite is very slow in neutral solution and the electrolysis could proceed to a saturated solution of hypochlorite were it not for the side reactions occurring in the cell. The most important reactions reducing the current efficiency and limiting the maximum amount of active chlorine obtainable from a given amount of salt are the reactions of hypochlorite ion ( $\text{ClO}$ ) at both the anode and cathode.

At the cathode hypochlorite ion is reduced by the hydrogen liberated there as follows:



Unless this reduction of  $\text{ClO}$  is prevented the reaction will proceed until the hypochlorite is being reduced as quickly as it is being formed. In commercial cells potassium chromate ( $\text{K}_2\text{CrO}_4$ ) is added to avoid this reduction. According to the theory the chromium ions form a protective diaphragm over the cathode which prevents the body of the solution containing the  $\text{ClO}$  ions from reaching the cathode. Acid or alkaline solutions will counteract this effect by dissolving the film formed over the electrode. Turkey Red oil together with calcium salts are used in place of  $\text{K}_2\text{CrO}_4$ . In this case, a film of hydrated lime formed by the calcium protects the cathode. The Turkey Red oil serves a similar purpose in protecting the anode.

At the anode, the maximum concentration of electrolytic hypochlorite obtainable is limited by the discharge of  $\text{ClO}$  ions. This reaction proceeds as follows:



The acids formed in the previously mentioned reactions are neutralized by the hydroxide formed simultaneously at the cathode. At stationary hypochlorite concentration, the rate of  $\text{ClO}$  formation will equal the rate of discharge of these ions. Maintaining an undisturbed "diffusion layer" at the anode will reduce the number of  $\text{ClO}$  ions reaching the anode. Agitation will break down this layer and permit the hypochlorite ion to reach the anode and be discharged as chlorate, reducing the hypochlorite concentration obtainable. In commercial cells, Turkey Red oil is employed to form a screen over the anode to reduce the discharge of hypochlorite ions.

High current density and high salt concentration increase the amount of chlorine liberated at the anode and hence reduce the chance of  $\text{ClO}$  ions reaching the anode and being discharged as chlorate. Materials from which the electrodes are fabricated also affect the hypochlorite concentration. Chlorine, for example, is more readily discharged from a platinized platinum electrode than



from other materials; hence, hypochlorite concentration will become higher before the hypochlorite ion is discharged as chlorate. Various other side reactions also occur in the cell, but do not proceed to any extent in neutral solutions of low temperature.

Optimum conditions for hypochlorite production may be summarized as follows: low temperature, neutral solutions, platinized electrodes, high current density, high salt concentration, and a provision for an undisturbed diffusion layer at the anode.

Practical considerations will affect the choice of conditions. For example, platinum electrodes are relatively expensive, high current densities produce undue temperature rise and result in shunt losses, the total amount of chlorine obtained per given amount of salt may be more important than current efficiency, and chromate or other depolarizing agents may form undesirable contaminants for certain purposes such as disinfection of drinking water and laundry use.

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Note: The following references were the chief sources of information reported herein:

A. J. Allmand and H. J. T. Ellingham, The Principles of Applied Electrochemistry (2nd ed.; New York: Longmans, Green, and Company, 1924), 366-391.

W. A. Koehler, Applications of Electrochemistry, Vol II, 3rd ed., 1935.



APPENDIX D

## PRELIMINARY LABORATORY TESTS





## REPORT ON

### CLOROCCEL ELECTROLYTIC HYPOCHLORITE CELL

#### I. INTRODUCTION

The object of the work described in this report was to determine whether or not the Paterson Clorocel electrolytic hypochlorite cell was capable of producing sodium hypochlorite, on a laboratory basis, from sea water and from sea water distillation apparatus overflow brine. Cell performance was evaluated on the basis of experimental determination of the following characteristics:

1. The effect of the dissolved solids content of sea water, and of distillation overflow brine on cell performance.
2. The effect of influent flow rates on chlorine production.
3. The effect of current consumption in the cell on cell economy.
4. The effect of the sodium chloride concentration of the influent on cell economy.

#### II. HISTORICAL (Omitted)

#### III. THEORETICAL (Omitted)

[Note by authors: In reproducing this report the historical and theoretical discussions have been omitted in order to avoid repetition of the material discussed in the body of the main report.]

#### IV. EXPERIMENTAL

##### 1. Apparatus, Equipment, and Materials.

a. The Clorocel electrolytic cell (Fig. 27 and Plate I), the subject of this report, is a component of the Clorocel SM/60 water purification unit, also known as the Clorocel Sterilizer Unit, Type SM/60, Serial No. 40014. The unit is manufactured by the Paterson Engineering Company, Ltd., of London, under British Patent No. 569,294. The cell consists of a pair of vertical carbon electrodes, semicircular in cross section, enclosed within a removable plastic case. A rotameter, calibrated to indicate flow rates of 0.4 to 0.6 liter per minute, is attached. The face of each electrode measures

6.20 inches by 2.93 inches. The space between the electrodes is 0.11 inch and, during operation, is maintained by a removable template which fits across the bottom of the electrodes. The effective area of each electrode is 18.135 square inches, equal to 1.17 square decimeters. This is equivalent to a current density on the electrode of 28.2 amperes per square decimeter for a current of 33 amperes. The cell tested is a spare cell, originally furnished with the Clorocel sterilizer unit loaned to the Navy Medical Research Institute by the International Filter Company, American representative of Paterson, Ltd. The cell was obtained for the Water Supply Branch through the efforts of Mr. W. L. Yarger, OCE, and Mr. E. M. Battey, International Filter Company.

b. A General Electric Copper Oxide Rectifier, Model 6RC10T, FL, 3-phase, 6-volt d-c, 500-ampere capacity, operating on 110-volt a-c current, loaned by the Electrical Engineering Branch, was used to reduce the available current, 110-volt a-c to 6-volt d-c to operate the cell. A double-throw triple pole switch was used to reverse electrode polarity (Fig. 28). At the start of the work the rectifier put out its rated capacity of 6-volts d-c. At the finish of the work its top output was 5.6 to 5.7 volts d-c, indicating probable deterioration. Amperages and voltages were determined by means of Weston instruments, checked for accuracy before and after the test period.

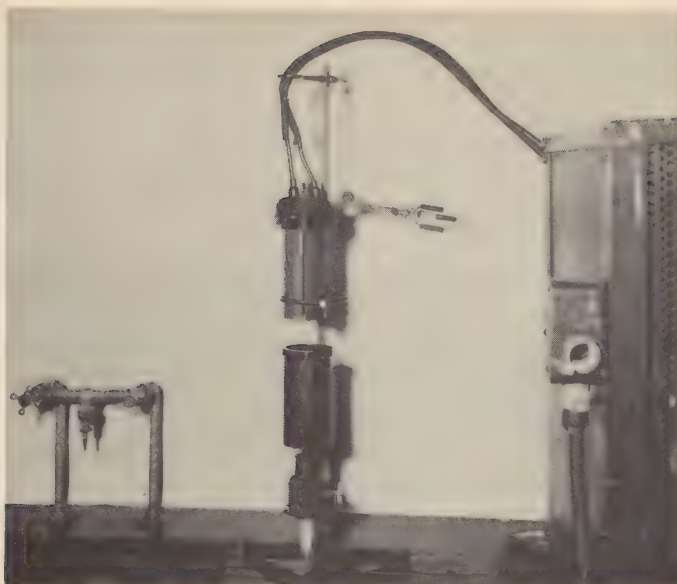
c. The apparatus (Fig. 29 and Plate II) for testing the cell was set up to permit continuous, constant-rate flow through the cell for periods up to 35 minutes. Sea water flowed by gravity from a 20-liter Pyrex glass carboy, equipped with a constant-head device, through a system of glass and rubber tubing to the cell. A system of glass and rubber tubing was arranged in such a way as to conduct the effluent from the cell to a point where samples could be obtained with the least possible loss of chlorine to the atmosphere. Flow rates were controlled by means of the needle valve and the rotameter furnished with the cell. The calibrations on the rotameter, intended for use with 10 percent salt solution, were checked with sea water. The results were as follows:

<u>Calibration</u>	<u>Actual Rate with Sea Water</u>
400 ml/min	435 ml/min
600 ml/min	640 ml/min

Loss of head for sea water at 23 C through the cell, including the needle valve and rotameter, was approximately 24 inches at the calibrated rate of 400 ml/min.

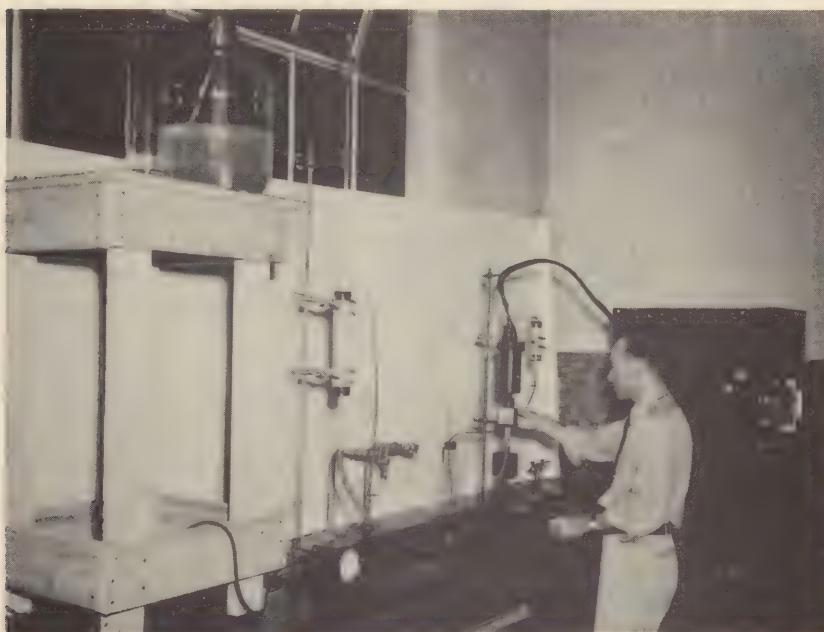
The sea water used for the tests was shipped from the Fort Story Distillation Test Station in 20-gallon glass carboys.





176-1-101

Plate I. Clorocel electrolytic cell. Removable plastic case dropped to show details of the carbon electrodes.



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Plate II. Clorocel electrolytic cell. Test set up permitting constant flow of brine solution to cell. Rectifier used as power source for testing is shown at the right behind the operator.

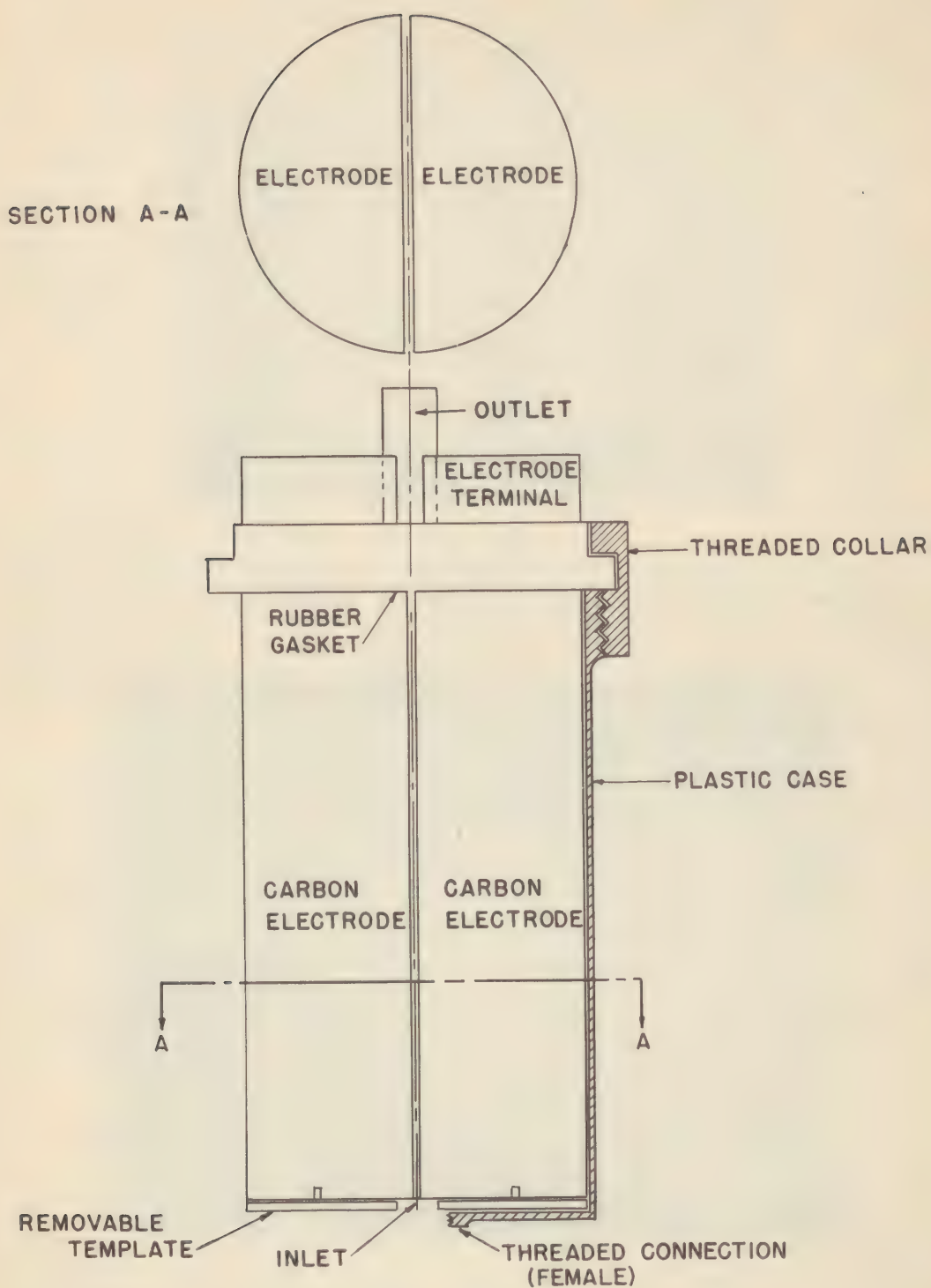


Fig. 27. Sketch of Clorocel electrolytic cell.

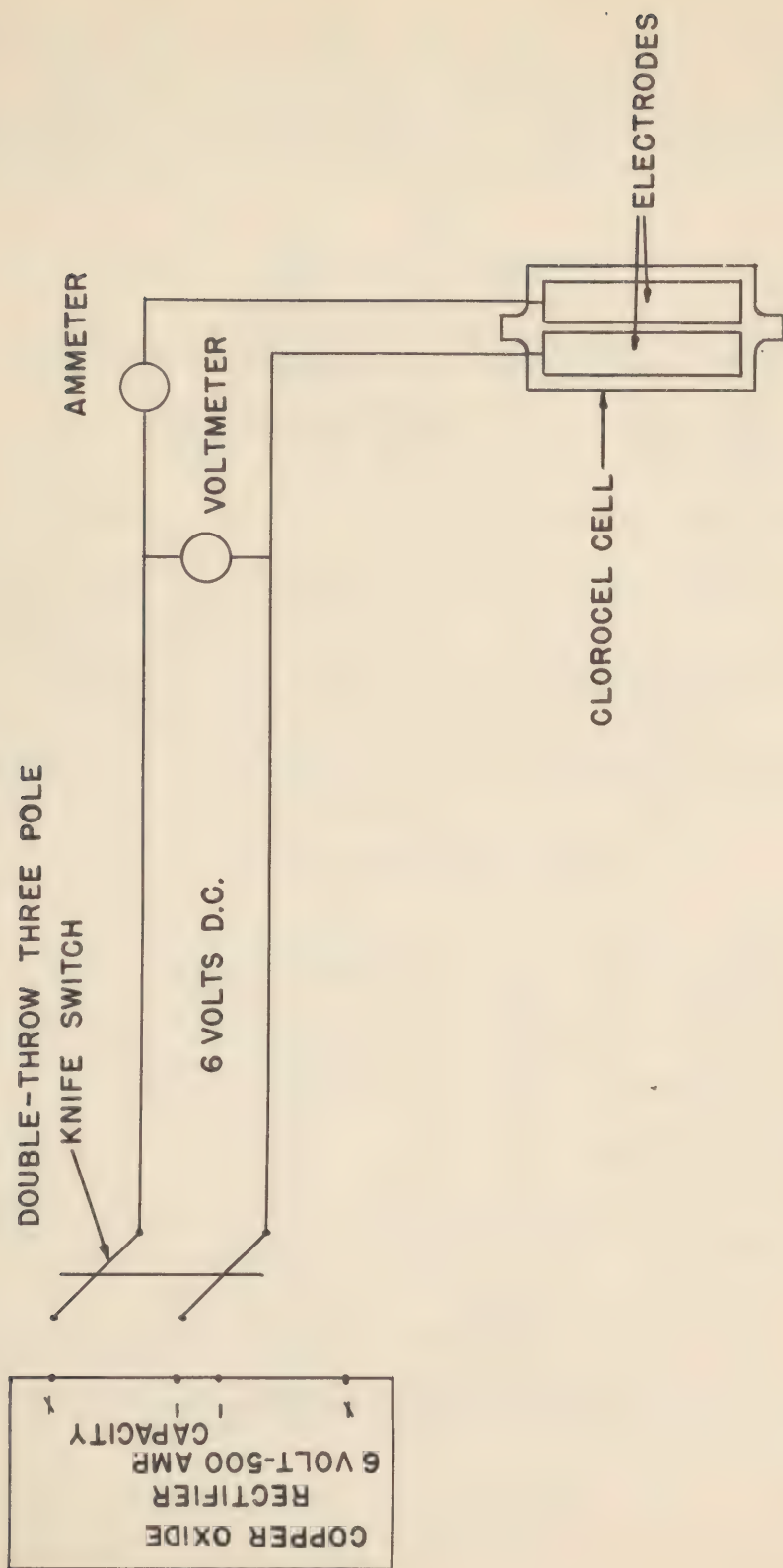


Fig. 28. Electrical layout for testing the Chlorocel cell.



The carboys were filled at high tide from the raw water pump discharge. Three different shipments of sea water were used. The interval between time of collection and time of use was between 3 and 8 weeks. The sea water was not filtered before use and was transferred from storage carboys to the 20-liter reservoir by air pressure.

#### Analyses of Sea Water

##### Shipment A:

Collected 10 April 1947

pH, 7.7

Sodium chloride,

22,400 ppm\*

##### Shipment B:

Collected 15 June 1947

pH, 7.9

Sodium chloride,

22,590 ppm\*

\* Determined by titration with 0.1 N silver nitrate.

The brine used for the tests was shipped from the Fort Story Distillation Test Station in glass carboys. It has been collected at the brine overflow outlet of a 1200 GPD thermocompression Distillation Unit, Badger Type, during runs on sea water and on sea water with alkalinity reduced to 30 ppm. Composite samples were prepared by mixing the contents of the carboys. The time interval between collection and use of the brine was approximately 2 weeks. The brine was neither filtered nor settled before use.

#### Analyses of Overflow Brine

##### Shipment A:

Sea water treated  
with acid

Collected 25 June 1947

pH, 7.9

Sodium chloride,

47,275 ppm

Turbidity, 40 ppm

##### Shipment B:

Sea water untreated

Collected 4 August 1947

pH, 8.05

Sodium chloride,

54,900 ppm

Sodium chloride solutions were prepared with ordinary commercial grade table salt. Analysis revealed:

% NaCl: 95

% Moisture: 4

Fort Belvoir tap water was used in making up the sodium chloride solutions:

pH: 8.3

Chloride: 5 ppm

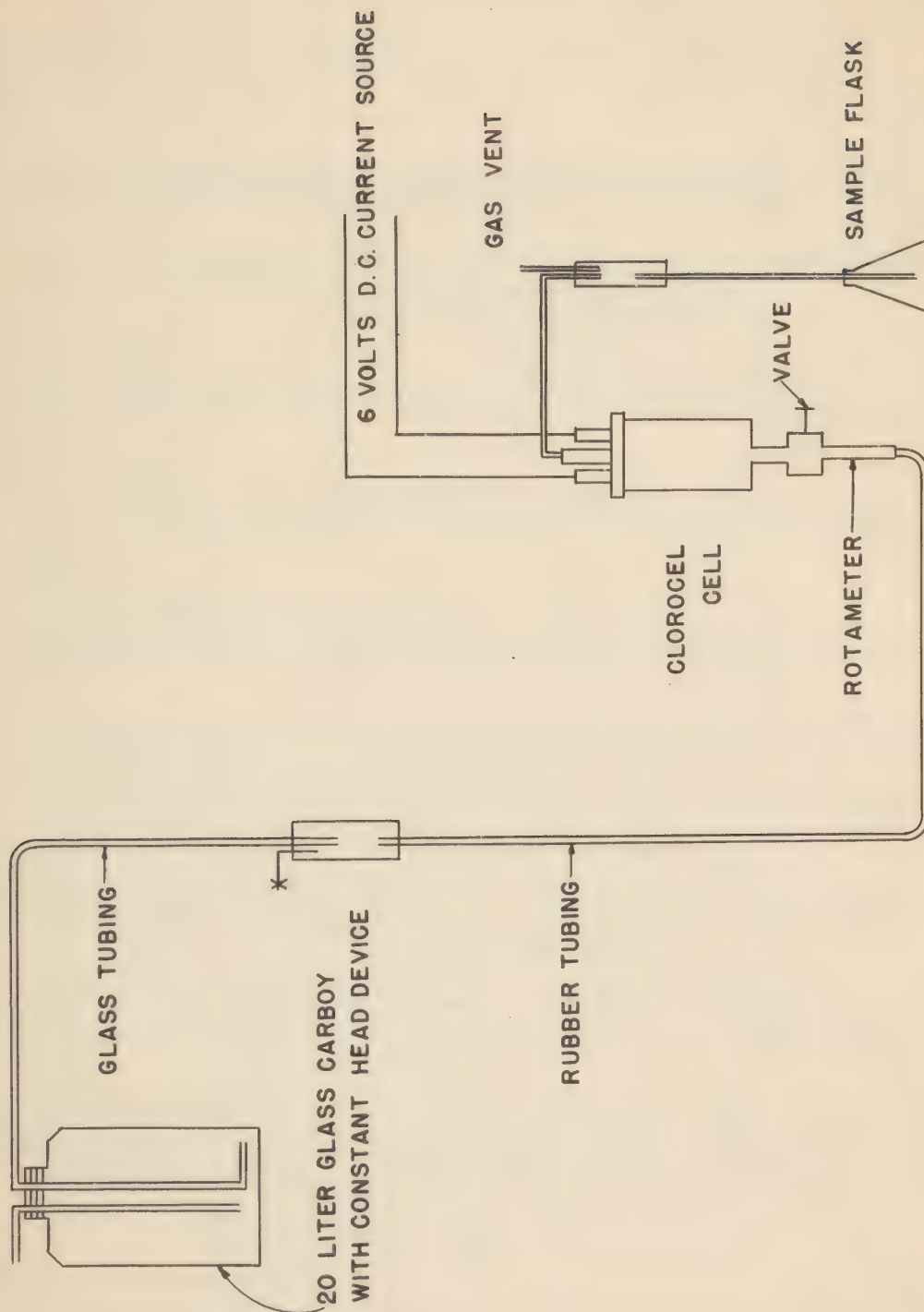


Fig. 29. Laboratory apparatus for testing the Clorocel cell.

2. Test Procedure. The procedure employed in testing cell performance follows:

a. The 20-liter glass carboy was filled with sea water or brine, and air pressure was used to transfer the liquid from the storage carboy.

b. Sample of sea water or brine in the 20-liter carboy was taken. Temperature, pH, and chloride were determined and recorded.

c. Flow through the cell was adjusted to the desired rate, based upon the rotameter calibrations.

d. Voltage output from the rectifier was adjusted to the desired value and the switch was thrown to pass the current through the cell.

e. At predetermined time intervals 600 ml portions of effluent were collected in Erlenmeyer flasks.

f. Electrode polarity was reversed at 5-minute intervals.

g. Voltage, amperage, and temperature of effluent were recorded at the time the sample was collected.

h. The amount of active chlorine in each sample was determined immediately after collection. The analytical procedure was based on that outlined by Kolthoff and Sandell<sup>1</sup> as follows:

(1) Transfer quantitatively a 100 ml aliquot of the collected sample to a glass stoppered Erlenmeyer flask.

(2) Add 6 ml of 6N H<sub>2</sub>SO<sub>4</sub>.

(3) Add 10 ml of 10% KI solution.

(4) Allow to react in dark for 5 minutes.

(5) Titrate the sample with 0.1 sodium thiosulfate using starch as an indicator. The thiosulfate had previously been accurately standardized against 0.1 N K<sub>2</sub> Cr<sub>2</sub>O<sub>7</sub>.

1. pH of collected samples was determined.

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1. I. M. Kolthoff and E. B. Sandell, Textbook of Quantitative Inorganic Analysis (New York: The Macmillan Company, 1936), 597-598.



Table XXX. Summary of Experimental Data on Chlorine Production and Current Consumption of the Chlorcel Electrolytic Cell

Run No.	Electrolyte	Volts-Amps Average	Current Consumption Average %	Flow Rate ml/min	Chlorine Conc. in Effluent mgs/liter	Amt. Chlorine Produced in 30 min. Grams	Amt. Chlorine Produced in 1 hr. Grams	Amt. of Chlorine Produced per Kilowatt Hour Grams
8	Sea Water-A	6.03	32.6	400	899	10.79	21.58	109.8
10	"	"	23.06	600	103	1.85	3.70	0.242
12	"	"	213.11	400	988	11.86	23.72	160.5
25	"	"	185.67	600	996	10.73	21.46	111.3
26	"	"	192.32	400	913	10.96	21.92	115.6
38	"	"	175.53	500	691	10.36	20.72	0.255
39	"	"	179.40	400	868	10.42	20.84	114.0
40*	"	"	187.20	500	797	11.95	23.90	118.0
41*	"	"	182.70	400	967	11.60	23.20	116.2
42*	"	"	181.20	600	656	11.80	23.60	127.7
9	"	"	105.16	400	572	6.86	13.73	0.280
11	"	"	52.27	400	330	3.96	7.91	130.2
13	"	"	22.56	400	185	2.22	4.43	0.287
14	"	"	53.14	400	361	4.33	8.66	130.5
15	"	"	103.53	400	609	7.30	14.60	151.4
16	"	"	22.20	400	183	2.19	4.39	154.4
43	"	"	175.20	500	731	10.96	21.92	196.4
27	Brine A	5.85	43.7	400	1589	19.07	38.14	162.9
28	"	"	32.66	400	311	3.74	7.47	141.1
29	"	"	69.89	400	595	7.14	14.28	141.1
30	"	"	262.25	600	1107	19.92	39.84	197.6
31	"	"	144.94	400	1076	12.91	25.82	0.329
32	"	"	264.32	400	1617	19.40	38.80	0.841
46	Brine B	5.62	46.6	400	1720	20.64	41.28	0.860
44	"	"	268.65	500	1440	21.60	43.20	0.893
45	"	"	282.90	600	1302	23.44	46.88	0.866
18	2.5% Salt	6.02	33.6	400	1066	12.79	25.58	157.6
19	"	"	202.27	400	1150	13.80	27.60	160.8
20	"	"	208.98	400	241	2.90	5.79	165.7
21	"	"	26.20	400	766	13.79	27.58	126.5
23	"	"	55.84	400	428	5.13	10.26	132.1
33	10% Salt	5.75	57.1	400	2587	31.04	62.08	221.0
34	"	"	42.00	400	516	6.19	12.37	136.0
35	"	"	97.69	400	1051	12.61	25.22	183.8
36	"	"	176.16	400	1707	20.48	40.96	189.1
37	"	"	37.88	400	441	5.33	10.59	294.6

NOTES: ‡ Values represent averages of four samples collected over a 30-minute period  
 \* All samples, except those marked with asterisk (\*), taken with current flowing in same direction  
 # Polarity on electrodes reversed at 5 minute intervals during all runs

j. The amount of chlorine present in the sample was calculated as follows:

$$\frac{\text{mg}}{\text{liter}} \text{ of chlorine} = \text{ml } 0.1 \text{ N sodium thiosulfate} \times 3.546 \\ \times \frac{1000}{\text{ml of sample}}$$

It may be noted that the majority of the runs were made at flow rates of 0.4 liter per minute in order to conserve sea water and brine. The remainder of the runs were at rates of 0.5 and 0.6 liter per minute. The voltages employed were 6.0  $\pm$ , 5.0  $\pm$ , 4.3  $\pm$ , 3.7  $\pm$ . Samples were collected one minute after electrode reversal, with current direction the same for each sample.

3. Test Results. The experimental data obtained in a number of runs with Fort Story sea water, distillation unit brine, 2.5 and 10 percent salt solutions, are presented in Tables XXX and XXXI.

Table XXX indicates the amount of chlorine produced and the amount of current consumed in various runs, with computations to show the cell economy.

Table XXXI indicates variations in the temperature, pH, and chlorine concentration of the cell effluent, as well as current consumption during several representative runs.

Inspection of cell components was made when the cell case was removed for cleaning of the electrodes following each run. No breakdown or deterioration of any of the components was evident to visual observation. The cell remained water-tight throughout the test period.

## V. DISCUSSION

4. Effect of Dissolved Solids in Sea Water and in Brine or Chlorine Production and Cell Economy. A comparison of the results obtained in runs Nos. 17 and 39 (Fig. 30 and Table XXXI) indicates that the dissolved solids present in sea water and in overflow brine reduce the chlorine output and current efficiency of the Clorocel. Examination of the electrodes following a 39-minute run without reversal of electrode polarity revealed that a mucilaginous white material had accumulated between the top portions of the electrodes. In comparable runs where the electrode polarity was reversed at 5-minute intervals, there was no evidence of a similar accumulation. Sanders,<sup>2</sup> reported that oxides of calcium and magnesium built up on

2. T. P. Sanders, "Electrolytic Chlorinator Used on East Texas Disposal Projects," *The Oil and Gas Journal* 41:31-32 (23 July 1942).

Table XXXI. Summary of Data on Variations in Temperature, pH, and Chlorine Concentration of the Effluent of the Chlorocel Cell

Electro-lyte	Run No.	TEMPERATURE			pH	Chlorine		Flow Rate
		Time : Min.	Degrees Centigrade	Rise : Degrees Centigrade		in Effluent : ppm	Current : Amps	
Sea Water A	12	0	26	24.6	7.7	-	-	-
	2			30.7	6.1	8.3	959	34.5
	11			30.8	6.2	8.5	965	400
	21			30.8	6.2	8.5	978	400
	31			30.8	6.2	8.45	963	400
Brine	27	0	25.7	24.0	7.9	-	-	-
	2			30.2	6.2	8.1	1559	42.5
	11			31.2	7.2	8.9	1593	400
	21			31.2	7.2	-	1602	400
	31			31.2	7.2	8.6	1603	400
	41			31.2	7.2	9.0	1573	400
2.5%	18	0	31	25.0	8.3	-	-	-
	1			31.9	6.9	8.4	1028	32.9
	11			31.8	6.8	9.0	1057	33.9
	20			31.8	6.8	9.25	1075	400
	38			31.9	6.9	9.15	1061	33.7
10%	33	0	27.7	24.0	8.3	-	-	-
	2			33.5	9.5	-	2606	57.0
	11			34.0	10.0	9.1	2494	57.0
	21			34.0	10.0	9.15	2587	400
	31			34.5	10.5	9.0	2656	57.2
	41			34.8	10.8	8.7	2731	57.4
Sea Water B	39	0	26.2	25	7.7	-	-	-
	2			30.3	5.3	-	891	29.8
	11			30.4	5.4	-	862	30.0
	21			30.5	5.5	-	861	30.0
	31			30.6	5.6	-	859	29.9
	39			30.7	5.7	-	859	29.7
Sea Water B	17	0	27	26.1	7.9	-	-	-
	1			32.1	6.0	-	866	32.3
	5			32.2	6.1	-	846	32.1
	11			32.3	6.2	-	794	31.9
	21			32.3	6.2	-	759	31.8
	30			32.5	6.4	-	733	31.3
	38			32.6	6.5	-	708	31.2



the cathode of the electrolytic cells used to chlorinate oil field brines.

Allmand and Ellingham<sup>3</sup> stated that calcium and magnesium hydroxides are deposited at the cathode of such a cell during the electrolysis of waters with higher mineral content.

The possibility of a slow but progressive poisoning of the electrodes by the dissolved solids present in the brine must be considered but cannot be answered on the basis of relatively small amount of brine passed through the cell (approximately 900 liters) during the period of the tests. A comparison of data in Table XXX shows a slight increase in resistance in the cell as the test progressed, as evidenced by a decrease in amperage values for a given voltage. Chlorine production but not cell economy shows a corresponding decrease. This question of the poisoning of the electrodes by brines could be answered only by the continuous operation of the cell over protracted periods.

5. Effect of Influent Temperature on Chlorine Production and Cell Economy. All samples were run through the cell at room temperature which ranged from 21 to 26 C. Heating samples to the higher temperatures necessary to simulate distillation unit brine was not practical in the laboratory. Data in Table XXXI show an approximate 6 degree temperature differential between influent and effluent with a slight gradual rise in effluent temperature over a 35-minute period (Fig. 31). This latter indicated that the flow rate of 0.4 to 0.6 liter per minute was capable of removing the heat generated by the reaction at the electrodes. Allmand and Ellingham<sup>4</sup> stated that an increase in influent temperature from 13 to 50 C of a 10 percent salt solution reduced the chlorine yield of the cell by 40 percent.

The Kellner horizontal hypochlorite cell was operated at 21 C, the Haas-Oettel cell at 22.5 C. Thompson<sup>5</sup> stated that low temperature is one of the conditions for making the highest concentration of hypochlorite.

6. The Effect of Flow Rate on Chlorine Production and on Cell Economy. Fig. 32 indicates that the rate of chlorine production varied inversely with the flow rates over the range of rates employed. Cell economy was very nearly a constant independent of flow rates.

3 and 4. A. J. Allmand and H. J. T. Ellingham, The Principles of Applied Electrochemistry (New York: Longmans, Green, and Company, 1942), 366-391.

5. Maurice de Kay Thompson, Theoretical and Applied Electrochemistry (3rd ed.; New York: The Macmillan Company, 1939), 289-297.

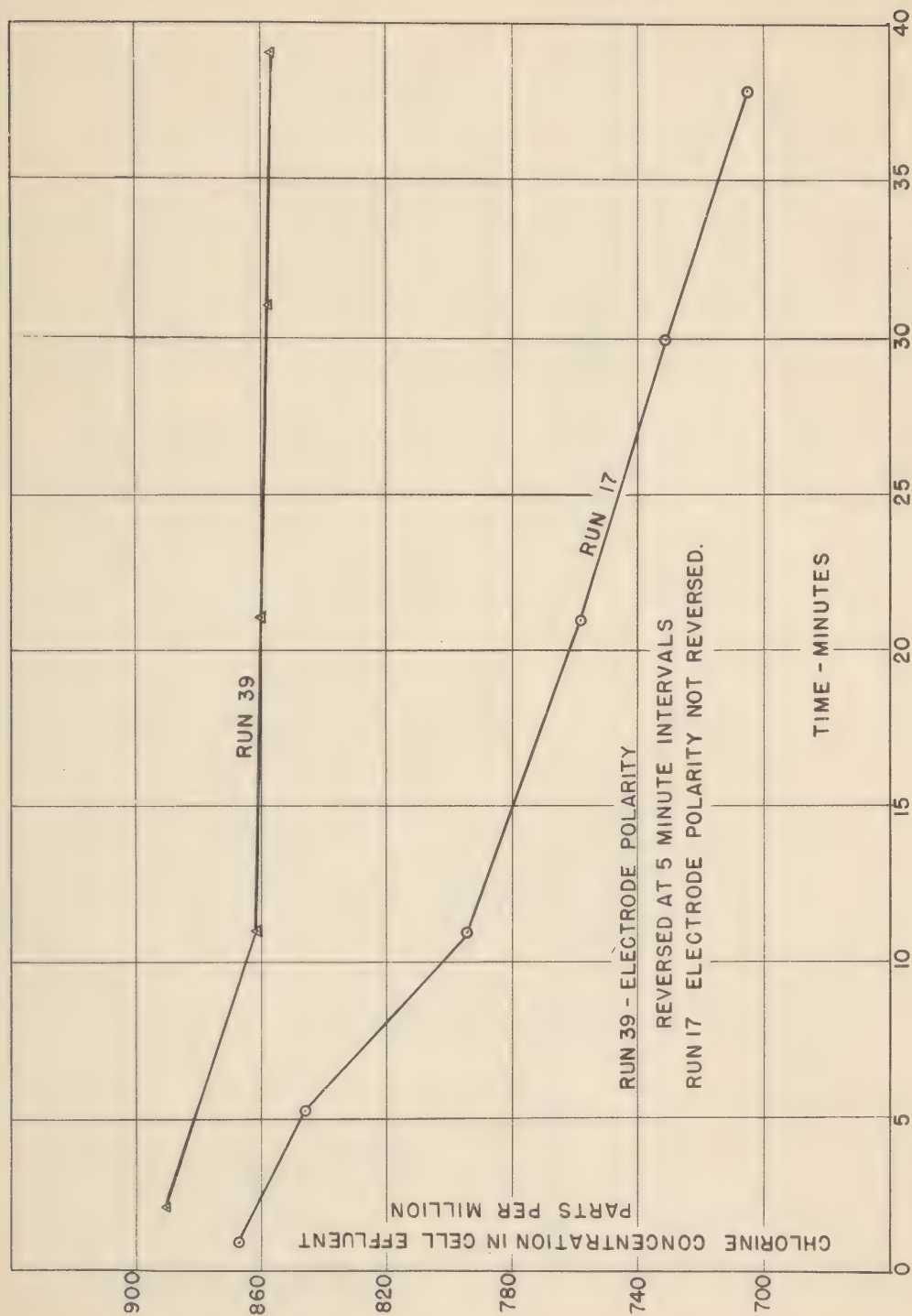


Fig. 30. Effect of sea water impurities on chlorine output of the Chlorocel cell.

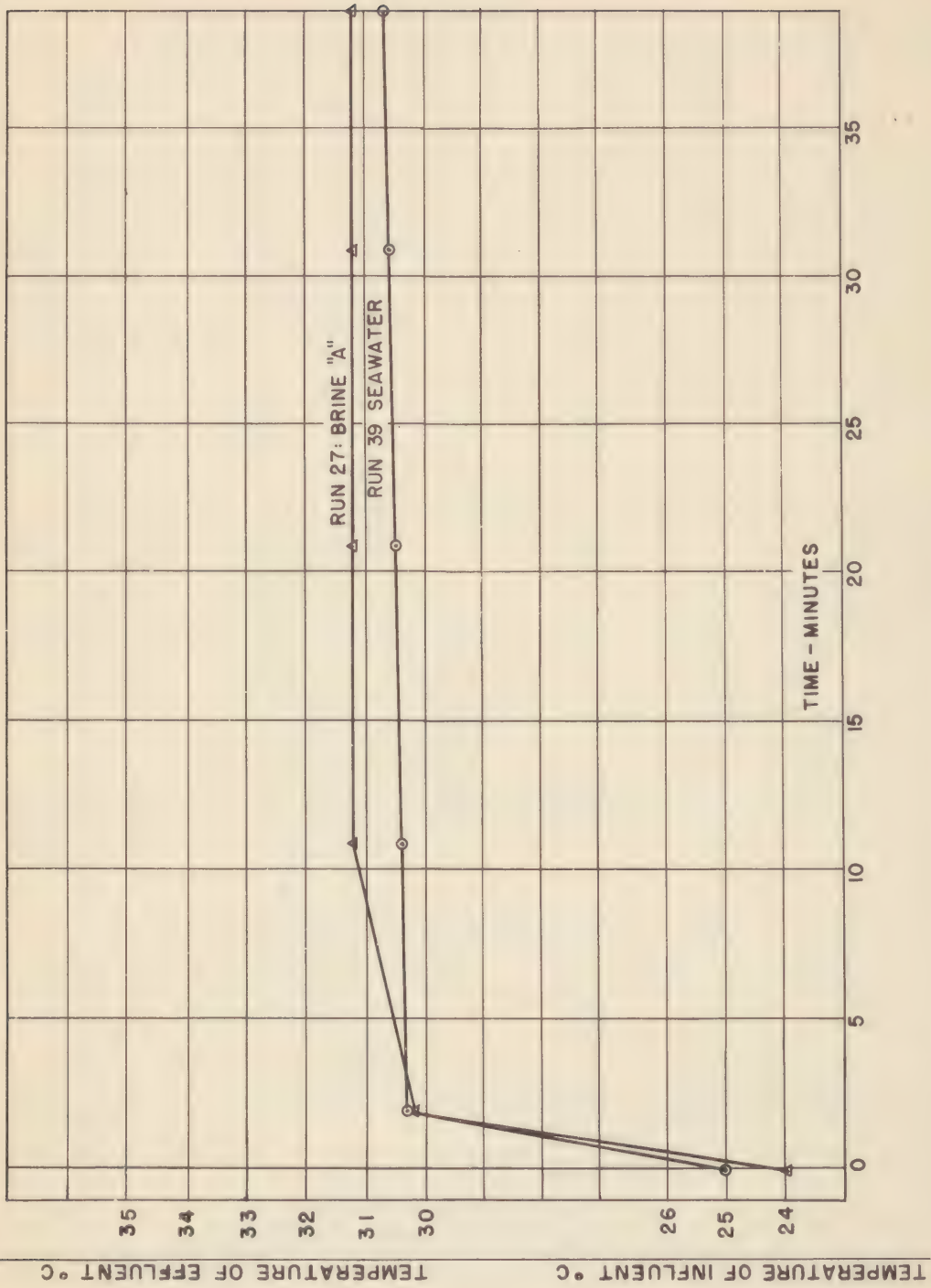


Fig. 31. Temperature rise in effluent of the Clorocel cell.



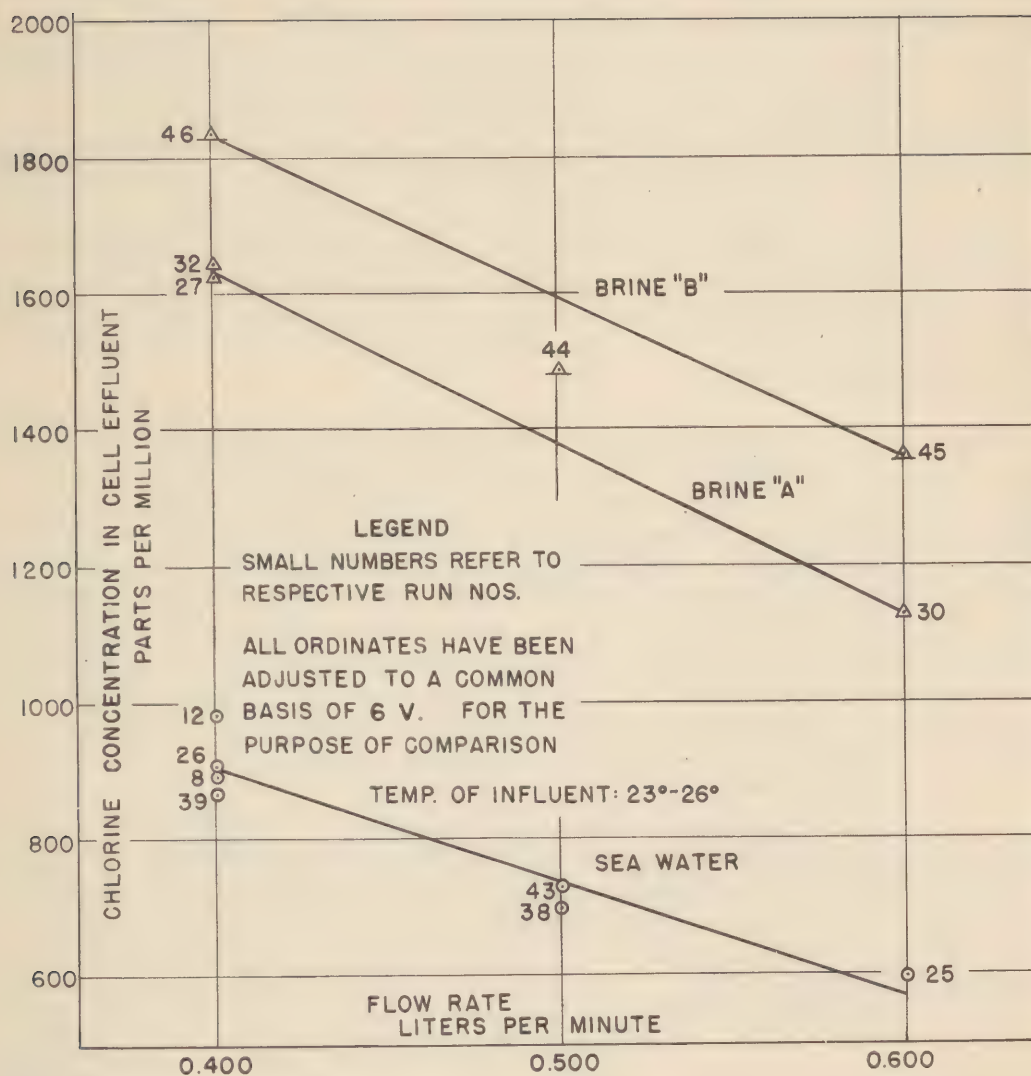


Fig. 32. Effect of flow rate on chlorine production in the Clorocel cell.

Slightly greater economy was obtained at 0.6 liter per minute than at 0.4 liter. This is indicated in Fig. 33. Recirculation of the effluent, as is practical in some of the commercial hypochlorite installations, is suggested by the manufacturer as a means of increasing utilization of the salt in the brine and of controlling chlorine concentration in the effluent. Since, as Allmand and Ellingham have pointed out, cell economy diminishes rapidly as the hypochlorite concentration in the effluent rises (Fig. 34) this greater utilization of salt is at the cost of increased current consumption. Recirculation is equivalent to a greatly reduced flow rate; hence, the use of the proper range of flow rates should make recirculation unnecessary as a means of controlling chlorine concentration in the effluent. In cases where unlimited quantities of sea water or overflow brine are available, utilization of electric current is more important than the salt saving. Recirculation of the effluent through the Clorocel would introduce the additional problem of cooling the cell.

7. Current Consumption. The theoretical decomposition voltage for sodium chloride in water solution, based on the Gibbs-Helmholtz equation, and taking into account the heats of formation, is 2.25 volts. Actually, considerably more voltage is required to overcome the resistance offered by the electrolyte: hence, commercial cells are operated at 3 to 5 volts. The term current efficiency designates the ratio of the amount of product actually formed to that which should theoretically have been formed on the basis of the ampere hours of current consumed. The term cell economy is the amount of chlorine produced per kilowatt hour of current consumed.

Results shown in Table XXX and Fig. 35 indicate an increase in cell economy from 0.25 to 0.44 pound chlorine per kilowatt hour as the operating voltage is reduced from 6 to 3.75. Following is a table in which is set forth the performance, at 6 volts, of the Clorocel and that described by Wallace and Tiernan in reporting their cell:

	<u>Wallace &amp; Tiernan</u>	<u>Clorocel- Sea</u>	<u>Clorocel- 2.5%</u>
<u>Lb Chlorine</u>	0.28	0.25	0.30
<u>KWH</u>			
<u>Lb Chlorine</u>	3.6	4.0	3.3
<u>KWH</u>			
<u>Kg Chlorine</u>	7.9	8.8	7.3

	<u>Wallace &amp; Tiernan</u>	<u>Clorocel- Sea</u>	<u>Clorocel- 2.5%</u>
<u>Gm Chlorine</u> <u>Amp Hour</u>	1.05	0.70	0.82
<u>Lb Salt</u> <u>Lb Chlorine</u>	18-20	-	33
<u>Gal Sea Water</u> <u>Lb Chlorine</u>	-	200	-
Hr to Produce 1 lb Cl <sub>2</sub>	200	21	16.5
<u>Lb Chlorine</u> <u>Hour</u>	0.005	0.047	0.061
<u>Lb Chlorine</u> <u>24 hours</u>	0.12	1.14	1.46

Data presented in Table XXX and plotted in Fig. 36 show that for each of the four solutions used, the rate of chlorine production under the test conditions was directly proportional to the amount of current consumed by the cell. Current efficiencies varied for each of the four solutions; for sea water 50 percent, for overflow brine 65 percent. These values may be obtained from Fig. 36 by setting up the ratio:

$$\frac{\text{ordinate actual chlorine production}}{\text{ordinate theoretical chlorine production}}$$

The rate of chlorine production of the Clorocel cell can be varied between a low of 100 ppm to a high of 980 ppm for sea water.

e. The release of the gaseous hydrogen formed in the cell to the atmosphere presents a hazard which would have to be corrected if the cell were used in the field.

## VI. CONCLUSIONS

### 8. Conclusions. It is concluded that:

a. The Clorocel cell is capable of producing sodium hypochlorite equivalent to active chlorine concentrations ranging from 100 to 950 ppm in sea water and from 300 to 1700 in distillation unit overflow brine passed through the cell at a rate of 0.4 liter per minute, over a period of 35 minutes, with reversal of



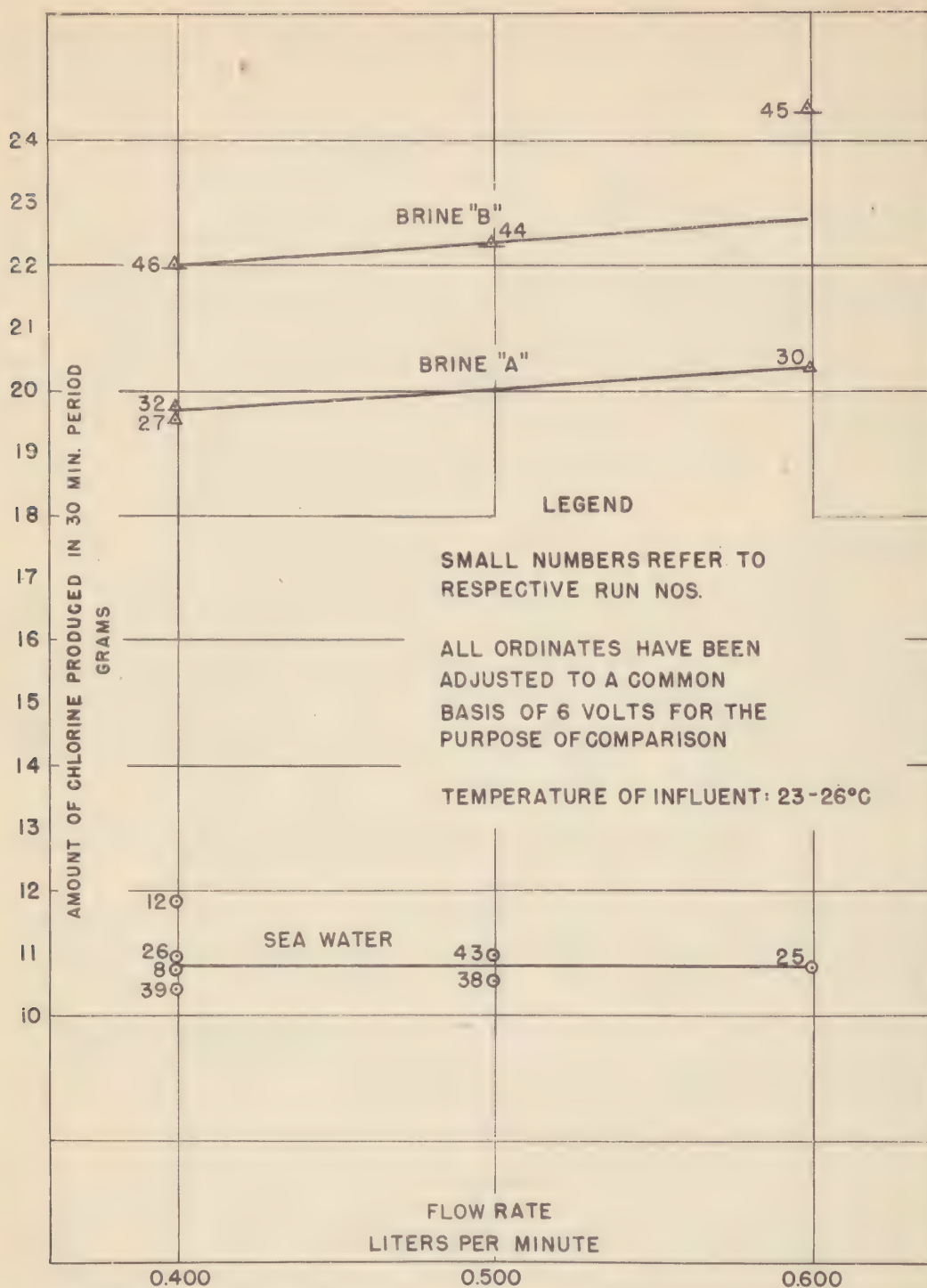


Fig. 33. Effect of flow rate on chlorine production in the Clorocel cell.

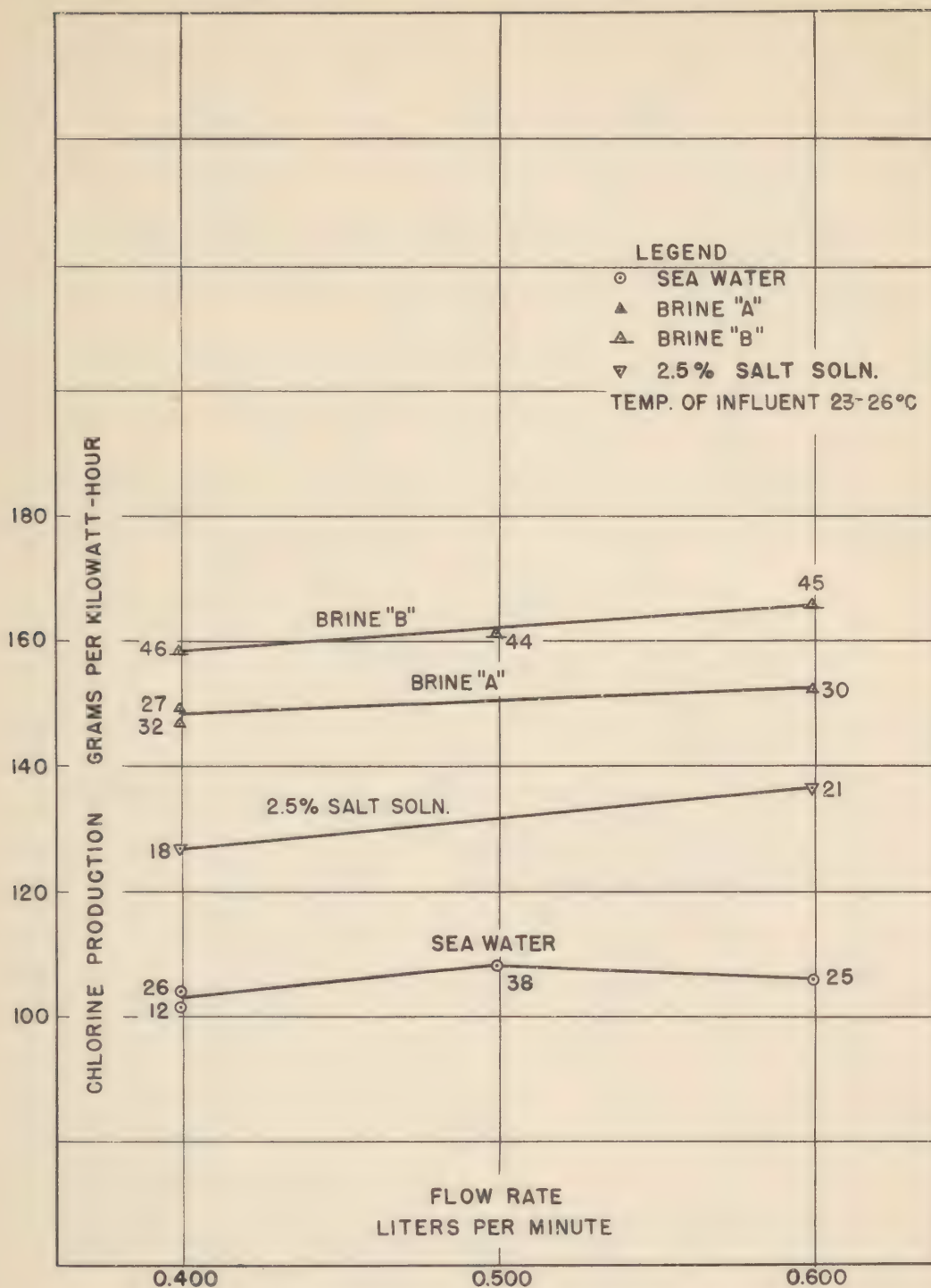


Fig. 34. Effect of flow rate on the cell economy in the Clorocel cell.

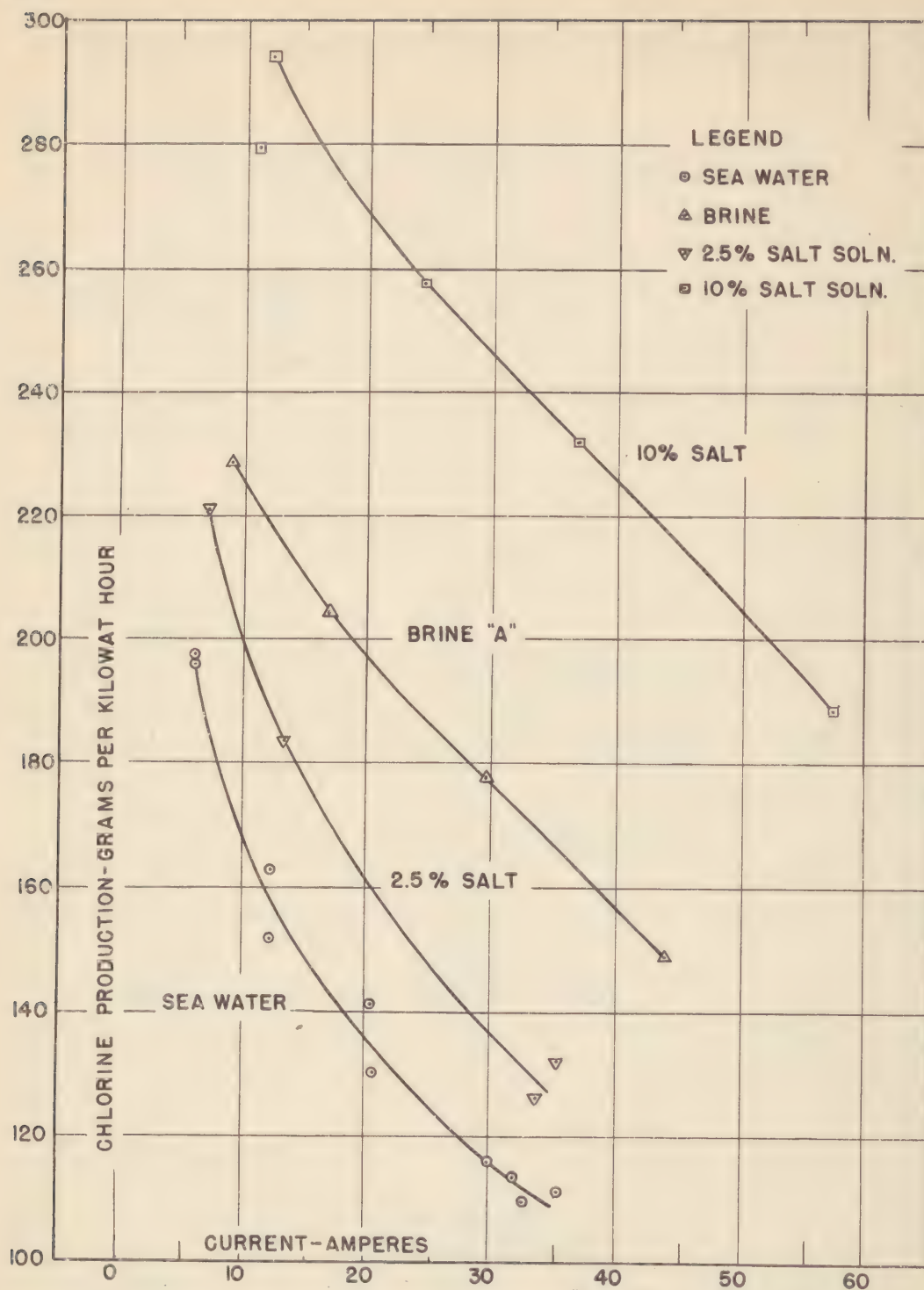


Fig. 35. Cell economy of the Clorocel.



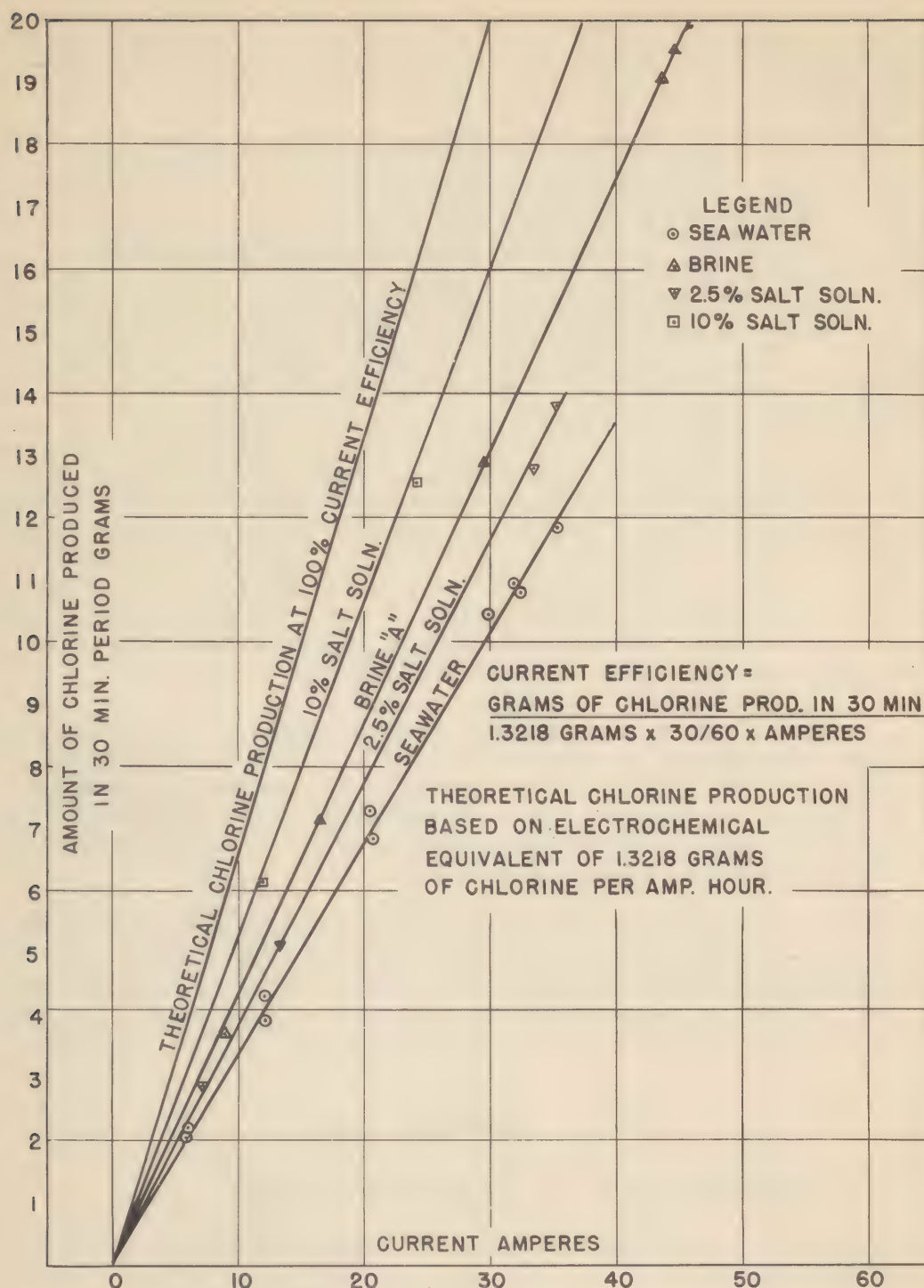


Fig. 36. Chlorine production and current efficiency of the Clorocel cell.

electrode polarity at 5-minute intervals. The cell can produce as much as 22 grams of active chlorine per hour from sea water and 47 grams from overflow brine. Rate of chlorine production is controlled by varying the cell voltage and the flow rate.

b. The dissolved solids in sea water and in distillation overflow brine significantly reduce the rate of chlorine production and the cell operating economy of the Clorocel hypochlorite cell. The reversal of electrode polarity at 5-minute intervals counteracts the effect of these impurities over periods of operation up to 35 minutes and maintains cell production and economy at a relatively constant level over this period. The effect of the dissolved solids in sea water and overflow brine on cell performance over longer periods of continuous operation remains to be determined.

c. The rate of production of chlorine in the Clorocel cell, for flow rates of 0.4 to 0.6 liter per minute, varies inversely with the rate of flow of sea water, overflow brine, or salt solution through the cell. Over this range the total amount of chlorine produced in a given period is a constant, independent of flow. Cell operating economy, in terms of pounds of chlorine per kilowatt hour of current consumed, likewise remains a constant, independent of flow rate, over the range 0.4 to 0.6 liter per minute.

d. The rate of production of chlorine in the Clorocel is directly proportional to the quantity of current passing through the cell over the range 12 to 60 amperes, for sea water, overflow brine, and salt solutions. Cell operating economy increases as the voltage is reduced from an upper limit of 6 volts toward the theoretical decomposition voltage of sodium chloride.

e. On the basis of observations made during and at the end of the test period cell construction and cell components are of a sufficiently durable nature as to warrant further investigation for the purpose of determining the breakdown characteristics of the cell.

## VII. RECOMMENDATIONS

### 9. Recommendations. It is recommended that:

a. No further laboratory tests of the Clorocel cell performance be conducted.

b. Tests be conducted at the Fort Story Test Station with sea water and overflow brine for the purpose of evaluating cell performance over longer periods of continuous operation than was possible in the laboratory.

c. Such tests include an investigation of:

- (1) Durability and life and cell components.
- (2) Rate of poisoning and/or disintegration of the electrodes.
- (3) Effect of higher brine influent temperatures, 120 to 140 F, on the plastic cell case.
- (4) Effect of higher brine influent temperatures on chlorine output and cell operating economy.

d. The status and results, if available, of tests, similar to those proposed at Fort Story, conducted by the Navy Department at Camp LeJeune, N. C., during the summer of 1947, be determined before beginning the Fort Story tests here recommended.

CHARLES D. GATES  
Engineer (Sanitary)





APPROVAL OF

Report 1108

EVALUATION OF

PATERSON CLOROCCEL STERILISER

1 April 1949

AND

DISTRIBUTION





ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES

THE ENGINEER CENTER AND FORT BELVOIR

FORT BELVOIR, VA.

ADDRESS REPLY TO

COMMANDING OFFICER

ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES

FORT BELVOIR, VA.

26 May 1949

IN REPLY  
REFER TO:

TECRD I  
400.1 (8-75-05-003)

SUBJECT: Transmittal of Report 1108, Evaluation of Paterson Clorocel Steriliser

THRU: Commanding General  
The Engineer Center and Fort Belvoir  
Fort Belvoir, Virginia

TO: Chief of Engineers  
Department of the Army  
ATTENTION: Chief, Engineer Research and Development Division

1. Transmitted herewith is Report 1108, "Evaluation of Paterson Clorocel Steriliser," dated 1 April 1949, which was prepared by the Technical Staff of the Engineer Research and Development Laboratories. This report covers the results of a laboratory and field evaluation of the Paterson Clorocel Steriliser, an electrolytic sodium hypochlorite producing unit.

2. The report concludes that:

- a. The Clorocel can be operated satisfactorily with sea water.
- b. The Clorocel is sufficiently simple in operation so that military personnel in the field can operate it with a minimum amount of training.
- c. The Clorocel can be operated satisfactorily with an automobile type d-c generator.
- d. High test calcium hypochlorite is superior to electrolytic sodium hypochlorite for military field use for the following reasons:

(1) It requires a lesser weight and volume of raw materials to produce a given amount of available chlorine than does the electrolytic method.

TECHD I

400.1 (8-75-05-003)

Subject: Transmittal of Report 1108, Evaluation of Paterson Clorecel Steriliser

(2) Special equipment such as an electrolytic cell, a generator, or other source of power is not needed.

e. Under conditions where the normal supply of calcium hypochlorite is exhausted and a ready supply of common salt or sea water is available, the Clorecel is considered a satisfactory emergency source of hypochlorite.

3. The report recommends that:

a. Current investigation of electrolytic sodium hypochlorite equipment be terminated.

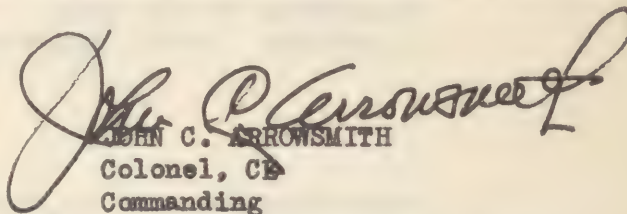
b. The unit be standardized if a future requirement for special military situations exists.

4. The report with its conclusions and recommendations is approved.

2 Incls

1. Proposed distr list

2. Rpt 1108

  
JOHN C. ARROWSMITH  
Colonel, CE  
Commanding

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*1st*  
Ind

Hq, The Engr Cen & Ft Belvoir, Ft Belvoir, Va.

27 May 1949

TO: C of Engrs, DA, Washington 25, D. C.

*01034*

SUBJECT: Transmittal of Report 1108, Evaluation of Paterson Clorocel Steriliser

ENGNC(26 May 1949)

2nd Ind

Office, Chief of Engineers, Washington 25, D. C., 14 June 1949

TO: The Commanding General, The Engineer Center, Fort Belvoir, Va.

1. The recommendations contained in paragraph 1 of the subject report and paragraph 3 of the basic communication are approved.

2. There is no foreseeable requirement for the clorocel unit which would justify classification of the item by the Corps of Engineers at this time.

3. The proposed distribution list is approved with the addition of copies for the Office of the Quartermaster General and the Chief of Transportation. The Transportation Corps's copy was forwarded by this Office as indicated by inclosed copy of transmittal letter.

BY ORDER OF THE CHIEF OF ENGINEERS:

3 Incls:

1 & 2 n/c

Added:

3. Cy Memo fm OCE to TC

dtd 14 June 49

*E. F. KLINKE*  
E. F. KLINKE  
Colonel, Corps of Engineers  
Acting Chief, Engr Res & Development Div  
Military Operations

TECAG 400.1

*3rd*

Ind

16 Jun 1949

Hq, The Engr Cen & Ft Belvoir, Ft Belvoir, Va.

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